63-2-4

UNITED STATES ARMY
COMBAT DEVELOPMENTS COMMAND

OFFICE OF SPECIAL WEAPONS DEVELOPMENT

FORT BLISS, TEXAS

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No. CDOG Study Project OSWD 62-5

FALLOUT FROM MULTIPLE SURFACE BURSTS

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OFFICE OF SPECIAL WEAPONS DEVELOPMENT
UNITED STATES ARMY COMBAT DEVELOPMENT COMMAND
Fort Bliss 16, Texas

FALLOUT FROM MULTIPLE SURFACE BURSTS

(CDOG Study Project OSWD 62-5)

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ABSTRACT

This study examines the effect of receiving fallout from more than one source on decay and total dose calculations and predictions and examines the adaptability of the current Army fallout prediction system to the multiple fallout situation. Simple procedures for the above situations are suggested for use in field situations.

FALLOUT FROM MULTIPLE SURFACE BURSTS
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1. PROBLEM.

To examine the effects of overlapping contamination fields of different ages on decay and total dose predictions and to examine the adaptibility of the current Army fallout prediction system to this situation.

2. DISCUSSION.

a. In many instances, current methods of computing fallout decay and total dose do not fully satisfy requirements for information when the fallout from one nuclear weapon is deposited in an area which is contaminated by the fallout from a previous nuclear detonation. Current methods of calculation for both the single fallout source and multiple source situation are discussed in Annex A. The problems associated with improving these methods and possible means of accomplishing this desired improvement are also discussed in this Annex.

b. The results obtained from the application of decay computation methods presented are valid for only the single points at which dose rate readings are taken. Computations using data from only one location cannot be used to predict future dose rates throughout an entire contamination plot.

c. There is a requirement in the Army for an improved fallout prediction system. The current prediction system is capable of defining general areas of hazard and permits the Army to utilize fallout as an offensive weapon in most instances. This system can sufficiently define the hazard area when fallout patterns overlap in a common area. The effect of overlapping patterns on the Army prediction capability is also discussed in detail in Annex A.

3. CONCLUSIONS.

a. Current methods of predicting fission product decay at a single location are inadequate in many cases if the activity at this location originates from more than one nuclear detonation.

b. Accurate methods of estimating single location decay for multiple fallout are time consuming and cumbersome unless sufficient data are available to permit the separation of the various contributors.

c. Simple methods of estimating single location decay from

multiple fallout, suitable for field use, are relatively inaccurate for long times, but can be revised from subsequent data to provide acceptable results.

d. When sufficient data are available to permit the separation of the different contributors to multiple fallout at a single location, the component method outlined in paragraph 8b of Annex A should be utilized to estimate future dose rates and total doses.

e. When the different contributions cannot be separated, future dose rates from multiple fallout should be estimated by a straight line interpolation on full logarithmic paper of measured dose rates as outlined in paragraph 9b of Annex A. This estimation should be revised by subsequent field readings at the location of interest.

f. Total doses from multiple fallout sources can be determined by a graphical integration method when the different contributions cannot be separated.

g. Although the current Army fallout prediction system was developed to predict for only a single detonation, it can predict hazard levels for multiple fallout with comparable reliability.

h. The hazard classification of an area where fallout prediction patterns overlap should be only that of the higher classification involved.

i. An improved Army fallout prediction system should include provision for accepting inputs from multiple contaminating detonations.

4. RECOMMENDATION.

It is recommended that the Commanding General, USACDC:

Approve this study as a guide for the inclusion of nuclear defense measures against fallout from multiple bursts in current doctrinal publications.

ANNEX A to Study - Fallout from Multiple Surface Bursts

DISCUSSION

SECTION I - INTRODUCTION

It would be difficult to envision a nuclear war in which fallout would not play a significant role. In spite of this, our ability to contend with fallout from several sources may be inadequate.

1. There has always been the possibility that the fallout at any one location could originate from more than one source. However, no one has come up with a completely satisfactory method, suitable for field use, of handling the decay, total dose, and prediction aspects of this problem. As a result, the current Army fallout prediction system and most published methods of estimating decay and accumulated radiation dose in an area contaminated by fission products (fallout) are based on the premise that the activity results from a single fallout producing burst.

2. A recent study (reference 1) recommended that the use of fallout as a weapon be considered a common use of a nuclear weapon when an advantage would result to friendly forces. The study was approved by the U. S. Continental Army Command. As a result of this study, revisions to the current doctrine of the Army concerning fallout were proposed. Reference 2 points out that the intentional use of fallout offers a means to extend greatly the casualty area of nuclear weapons. The directive lists the potential uses for intentional fallout described in the above study and directs that the employment of fallout-producing bursts may be considered to be a normal use of nuclear weapons, to be employed by commanders in all cases where a tactical advantage will be achieved. There is no reason to believe that fallout will not be used against us in the same manner as the advantage which would accrue from such use would be obvious to any nation.

3. With this expected increase in the use of fallout there will be a corresponding increase in the areas on the battlefield which will be subject to receiving fallout from more than one detonation. Overlapping fallout patterns will normally result when one fallout producing burst is fired upwind or downwind from another. However, that is not the only situation which will result in an overlap. When two bursts are separated in time, a change in wind direction can result in an overlap. An overlap can occur even from two patterns that would be expected to be parallel if there is a considerable difference in the yields. Wind shear, a change in wind direction with altitude, can

cause the patterns from two different yield weapons to lie in different directions due to the corresponding differences in cloud height.

4. It should be emphasized that the results obtained from the application of the decay computation methods discussed in this Annex are valid for only the single point at which dose rate measurements are made. Computations pertaining to this point cannot be used to predict future dose rates throughout a complete fallout contamination plot. This is unlike the single burst situation where the decay rate computed may be used anywhere throughout the contaminated area.

SECTION II - FALLOUT DECAY AND TOTAL DOSE CALCULATIONS

5. The decay of fission product activity is described in general by the Kaufman equation (reference 3):

$$R_A t_A{}^n = R_E t_B{}^n \tag{1}$$

where R_A = Dose rate at time A.

R_B = Dose rate at time B.

t_A and t_B = Times in hours, measured from the time of the detonation.

n = A constant, referred to as the decay constant.

In common usage, a reference dose rate is taken as the dose rate at one hour after the detonation. Substituting one hour for time B results in:

$$R_A t_A{}^n = R_1 (1)^n = R_1$$

$$R_A = \frac{R_1}{t_A{}^n} = R_1 t_A{}^{-n} \tag{2}$$

That is, the dose rate at any time, A, is equal to the dose rate at one hour multiplied by the time, A, in hours, raised to the -n power. This expression is more commonly written as:

$$R = R_1 t^{-n} \tag{3}$$

Studies of the fission product activity resulting from many nuclear explosions have concluded that a good average value for n, for times of tactical interest, is 1.2, thus the final equation is written as:

$$R = R_1 t^{-1.2} \tag{4}$$

The dose which an individual receives while exposed to a radiation source is equal to the product of the dose rate at the time of the exposure and the length of the exposure. That is:

$$D = Rt \tag{5}$$

However, when the source of the radiation is fission product activity, the dose rate is not a constant, but varies with time as described in equation (4). Thus, the dose accrued from the exposure must be calculated by integrating the varying dose rate over the time of exposure. The dose accumulated by an exposure from time A to time B, both times measured from the time of detonation, would be represented by the integral:

$$D = \int_A^B R_1 t^{-1.2} dt \tag{6}$$

when integrated this becomes:

$$D = R_1 \left[\frac{t^{-0.2}}{-0.2} \right]_A^B$$

or

$$D = 5\ R_1 \left(\frac{1}{t_A^{0.2}} - \frac{1}{t_B^{0.2}} \right) \tag{7}$$

It is these relationships, equations (4) and (7), which are used in the form of nomograms, graphs, or tables in current nuclear weapon employment and radiological defense literature for fallout decay and total dose calculations. However, these relationships are applicable only when all of the activity under consideration results from a single detonation. When the activity at any one location results from more than one detonation, the dose rate at that location would be the sum of the individual dose rates resulting from each detonation. The dose rate at any time in such a location, following fallout-producing bursts X and Y would be:

$$R = R_{1X} t_X^{-1.2} + R_{1Y} t_Y^{-1.2} \tag{8}$$

and the dose accumulated from an exposure to this activity would be calculated by integrating equation (8) over the time of exposure. Equations of this nature are not as readily reduced to nomograms, graphs or tables, as were the equations describing fallout from a single source. An attempt was made to produce a numerical solution to this problem which could be reduced to a simple field method (reference 4). The resulting equations were not suitable for field use.

Apparently, no other attempt has been made to solve this problem simply for the general case, where the times of the two detonations and the relative fraction of the activity contributed by each burst are unknown.

6. When the two bursts are simultaneous, the problem simplifies itself to the more easily handled single burst situation. In equation (8):

$$R = R_{1X}t_X^{-1.2} + R_{1Y}t_Y^{-1.2}$$

both times would be measured from the same time of detonation. Thus:

$$t_X = t_Y = t$$

$$\text{and} \quad R = (R_{1X} + R_{1Y})\ t^{-1.2}$$

Since R_{1X} and R_{1Y} are constants, their sum is merely a new constant which we can represent as R_1 for the combined fallout depositions. Thus, a measurement of the dose rate at any time could be normalized to this combined reference dose rate and the dose rate at any other time could then be calculated by the methods utilized when the fallout is from one source. Similarly, the total dose received between any two times after the time of the bursts could also be calculated by any of the published methods for the single burst situation. Therefore, when the times of detonation are the same, or nearly so, currently published methods are satisfactory. One need only assume all of the activity is from a single source, of the indicated age, and proceed accordingly. How close the detonations must be in time for this approximation to be satisfactory is not known precisely, but one reference has indicated that two hours is sufficiently close (reference 5). This appears to be a reasonable assumption when the errors inherent in tactical instruments are considered.

7. When the time between bursts is greater than two hours, the problem is considerably more difficult. Equation (8):

$$R = R_{1X}t_X^{-1.2} + R_{1Y}t_Y^{-1.2}$$

cannot be simplified by arbitrary assumptions. Because there are now four unknowns in this equation, simple manual means of solving the equations, amenable to field use, do not exist unless two or more of the unknowns can be determined separately. The solution to the problem, if this is the case, will be discussed in a following paragraph. The more general case, however, is encountering a fallout field consisting of contributions from two or more bursts occurring at unknown times with the relative contributions from each burst unknown. There is no simple way to handle this situation available today for field use.

8. Current methods for solving the general case discussed in paragraph 7 above are time consuming and cumbersome.

a. One method of predicting decay for the general case has been published (reference 5). In this method a "characteristic curve" is drawn for each case on the basis of hourly values of the radiation intensity and this curve is then compared with standard theoretical curves presented in the report. As a result of this curve-matching an "effective" decay rate and an "effective" time of origin are arrived at. By this means, combined fallout from two or more explosions is treated as fallout from a single "equivalent" explosion with an appropriate decay rate and predictions of future radiation intensities are made accordingly. For clarity, this method will be designated the Canadian method for the balance of this report. This method gives results which are well within acceptable accuracy limits, less than 10% error, for tactical applications. However, the method is time consuming, requiring readings over a number of hours, and requires a considerable amount of plotting, data-smoothing, comparison with standard curves, and mathematical computation. For this reason a simpler and faster method would be desirable for field use. Some relaxation on accuracy would be acceptable to achieve this goal. An example of this method is presented in Appendix 1 to this annex.

b. One other method currently available (Reference 8) for solving the multiple burst decay and total dose calculation problem requires that the contribution from the first fallout event be measured prior to the arrival of the second contribution. If the time of the first detonation is known, and at least one reading is available for the location of interest after the fallout peaks, then the magnitude of this contribution can be calculated for any other time at that location using the methods outlined above for single contributors. This calculated value can then be subtracted from the total reading at that location at any future time. The difference will be the contribution from the second detonation. Single source methods in use today can then be applied to each contribution separately to estimate dose rates or exposure doses for any future times. The sum of the separately predicted dose rates or dose values will be the predicted total values for those future times. This method requires no new procedures and can be easily handled by anyone trained in current procedures. This method will be designated the component method throughout the balance of the report. An example of this method is shown in Appendix 2 to this annex. However, as was mentioned above, enough must be known about the first fallout source to permit handling the contributions separately. When the detonations are sufficiently separated in time, standard monitoring and survey procedures will normally establish the necessary characteristics of the first fallout pattern and permit this method to be effectively utilized. For an area of interest, the pattern would normally be determined within perhaps 7-8 hours after a burst. Therefore, if the second burst occurs eight or more hours after the first, this

method should be sufficient.

9. Other approaches to the solution of this problem are possible.

a. There is an Army funded project in the nuclear defense research program to investigate one phase of this problem. The proposed project will be an attempt to develop a simple, transistorized instrument to determine the age of a fallout field and to possibly separate the contributions when the fallout field consists of activity from more than one source. The instrument will determine this information from the observation of a few characteristic peaks in the residual gamma spectrum of mixed fission product. The development is considered by the U. S. Army Nuclear Defense Laboratory to be within the state of the art. Whether the equipment will be sufficiently reliable and economically feasible remains to be determined. Such an instrument would permit the relatively easy separation of sources method of calculation discussed previously.

b. Another possible, and far simpler, solution would be to find an approximation, which could be simply performed in the field, and which would give an acceptable answer to the decay or total dose problem. Two approximations of this type are readily apparent.

(1) One would be to merely assume that all of the activity at any location came from only one source and estimate future dose rates by using single source decay methods (n = 1.2). For this method, some likely time of burst must also be assumed. This method will be designated the combined method throughout the balance of the report.

(2) The other method would require two or more readings of the actual dose rate at the location of interest. These readings would be plotted against time on full logarithmic (log-log) graph paper. A straight line plotted through the points would be extended to later times and the future dose rates of interest read directly from the graph. This method will be designated the extrapolation method in the balance of the report.

(3) In order to illustrate these two methods, figures A-1 through A-20 were prepared. The rate of decay of fallout from multiple sources will vary primarily with the relative contributions of the different sources and the time between source explosions. For these reasons, figures were included for twenty different combinations. These include relative contributions of 1:10, 1:15, 1:1, 5:1, and 10:1 and for separation times from two hours to eight hours. On each graph there are three lines. The line labeled "A" represents the actual dose

rate readings that would be measured under the initial conditions specified in the legend. The line labeled "B" represents the dose rates that would be predicted using the combined method and a reference time of the second burst. The line labeled "C" represents the dose rates that would be predicted by the extrapolation method using the first two dose rates plotted. Table A-1 shows a sample of the calculated data utilized in the construction of these figures.

TABLE A-1

Sample of Data Used for Figures A-1 Through A-20
(Specific data indicated are taken from Figure A-13)

R_{1X} = 1000 rad/hr, R_{1Y} = 200 rad/hr, 2 hour separation.

Time after 1st burst (hours)	Time after 2d burst (hours)	Dose rate frm 1st burst (rad/hr)	Dose rate frm 2d burst (rad/hr)	Total dose rate, Line A (rad/hr)	Dose rate frm Combined method Line B (rad/hr)
1	-	1000	-	1000	-
2	-	430	-	430	-
3	1	260	200	460	-
4	2	190	86	276	198
5	3	140	52	192	120
6	4	110	38	148	87
7	5	95	28	123	64
8	6	80	22	102	51
9	7	70	19	89	44
10	8	60	16	76	37
12	10	50	12	62	28
14	12	40	10	50	23
16	14	35	8	43	18
20	18	27	6	33	14
24	22	21	4.8	25.8	11
30	28	16	3.4	19.4	8
36	34	13	2.8	15.8	6
42	40	10	2.3	12.3	5
48	46	9.5	2.0	11.5	4.5

Figure A-1. R_{1X} = 100 rad/hr, R_{1Y} = 1000 rad/hr, 2 Hour Separation

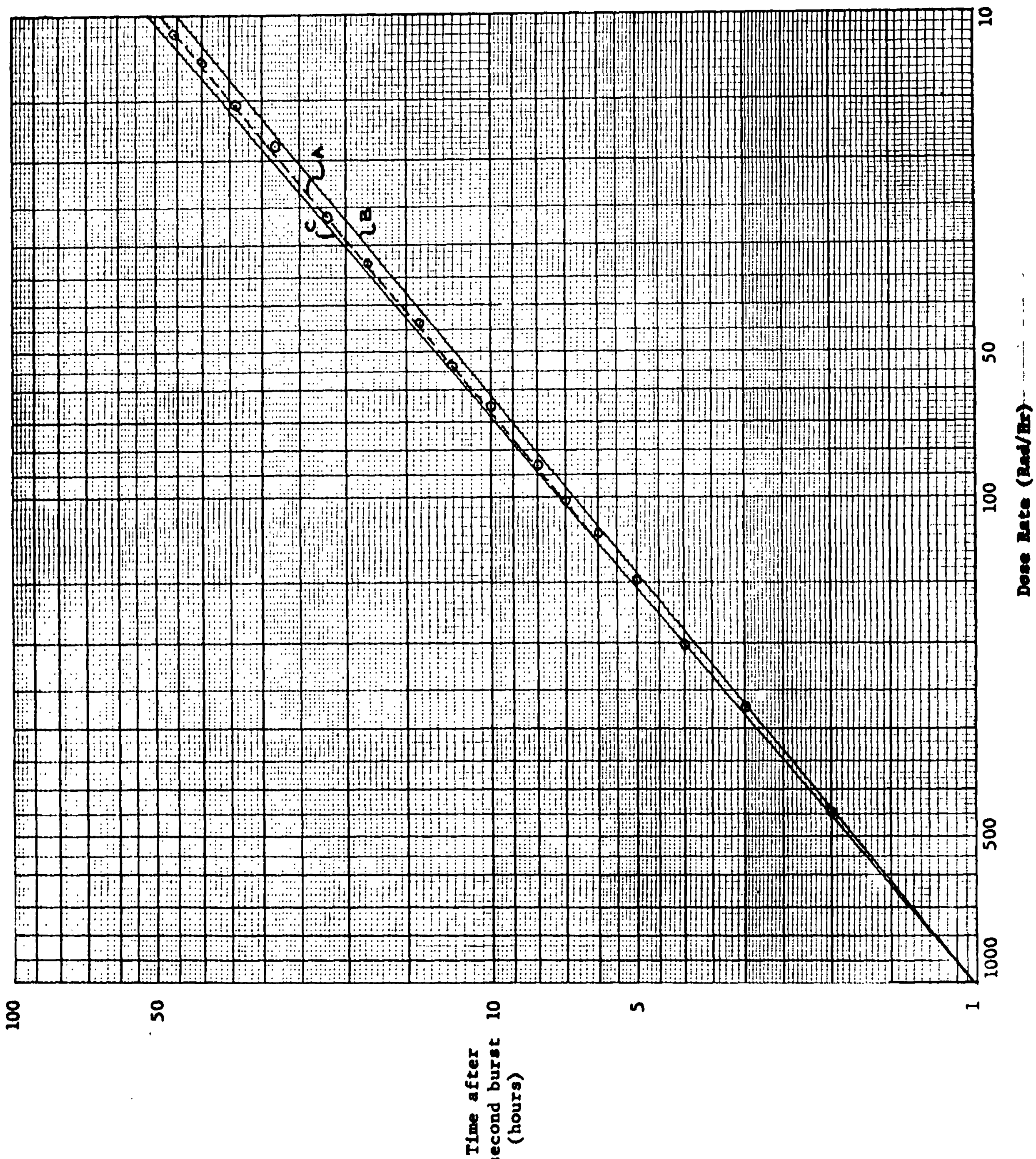


Figure A-2. R_{1X} = 100 rad/hr, R_{1Y} = 1000 rad/hr, 4 Hour Separation

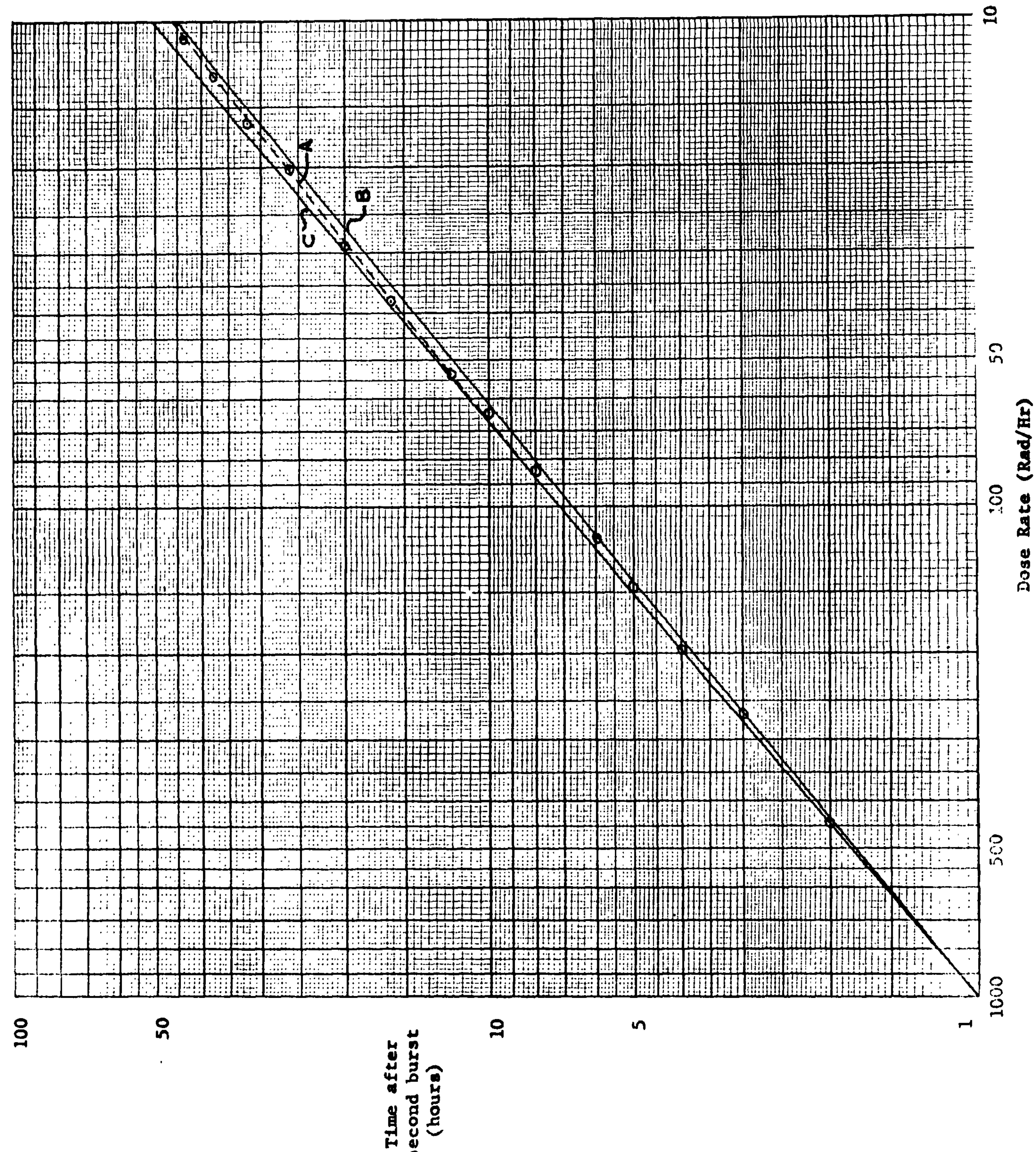


Figure A-3. R_{1X} = 100 rad/hr, R_{1Y} = 1000 rad/hr, 6 Hour Separation

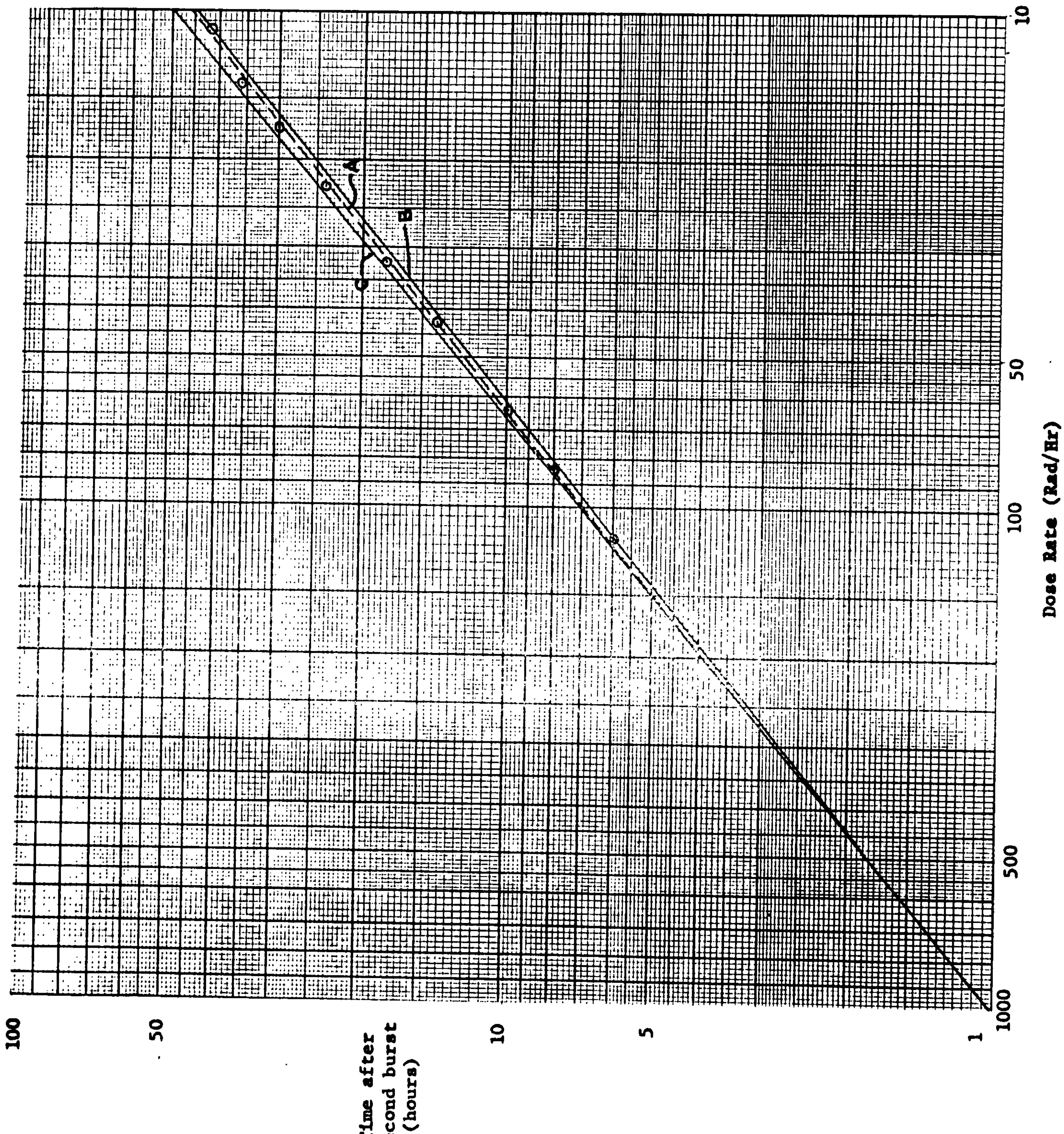


Figure A-4. R_{1X} = 100 rad/hr, R_{1Y} = 1000 rad/hr, 8 Hour Separation

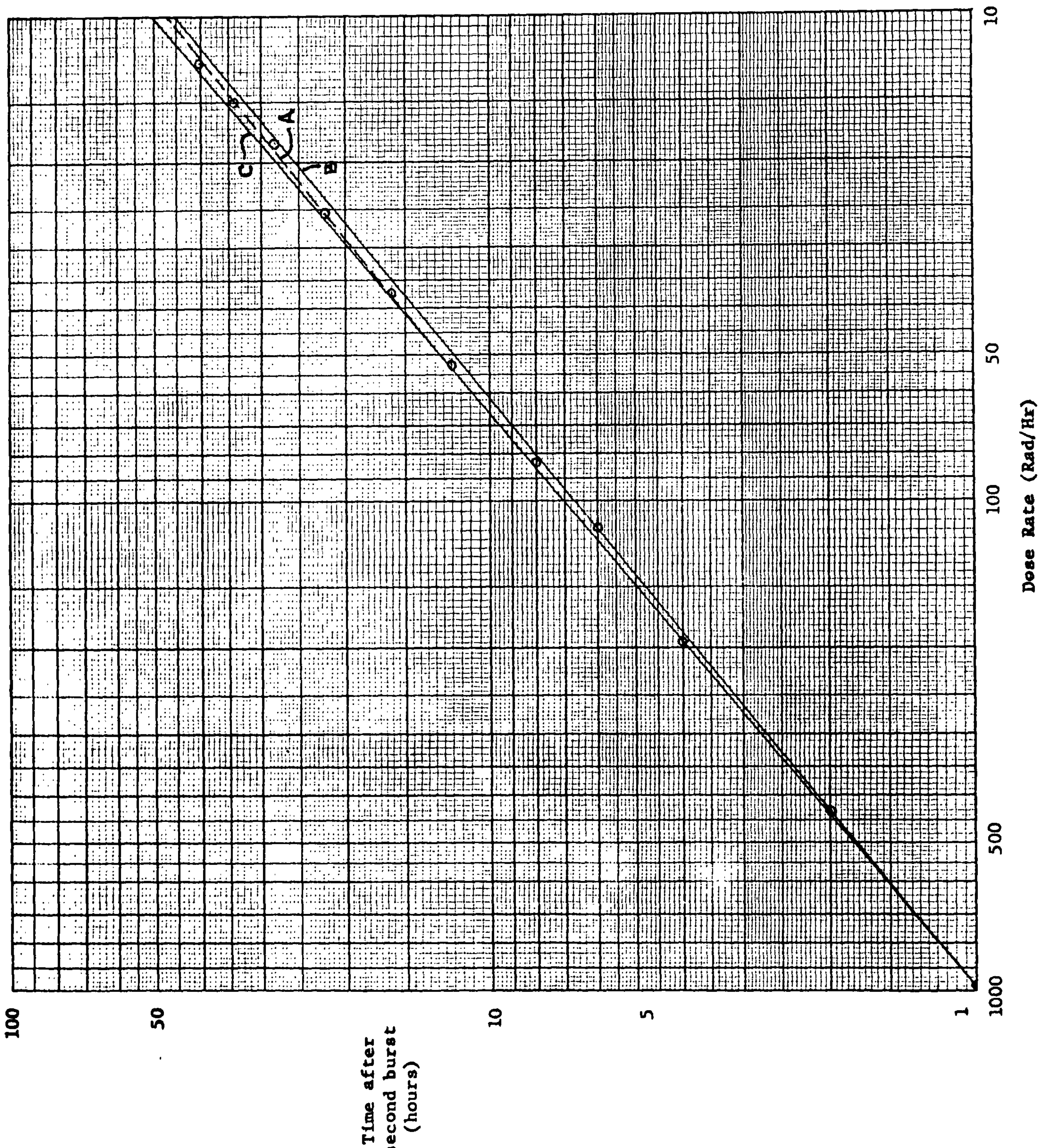


Figure A-5. R_{1X} = 200 rad/hr, R_{1Y} = 1000 rad/hr, 2 Hour Separation

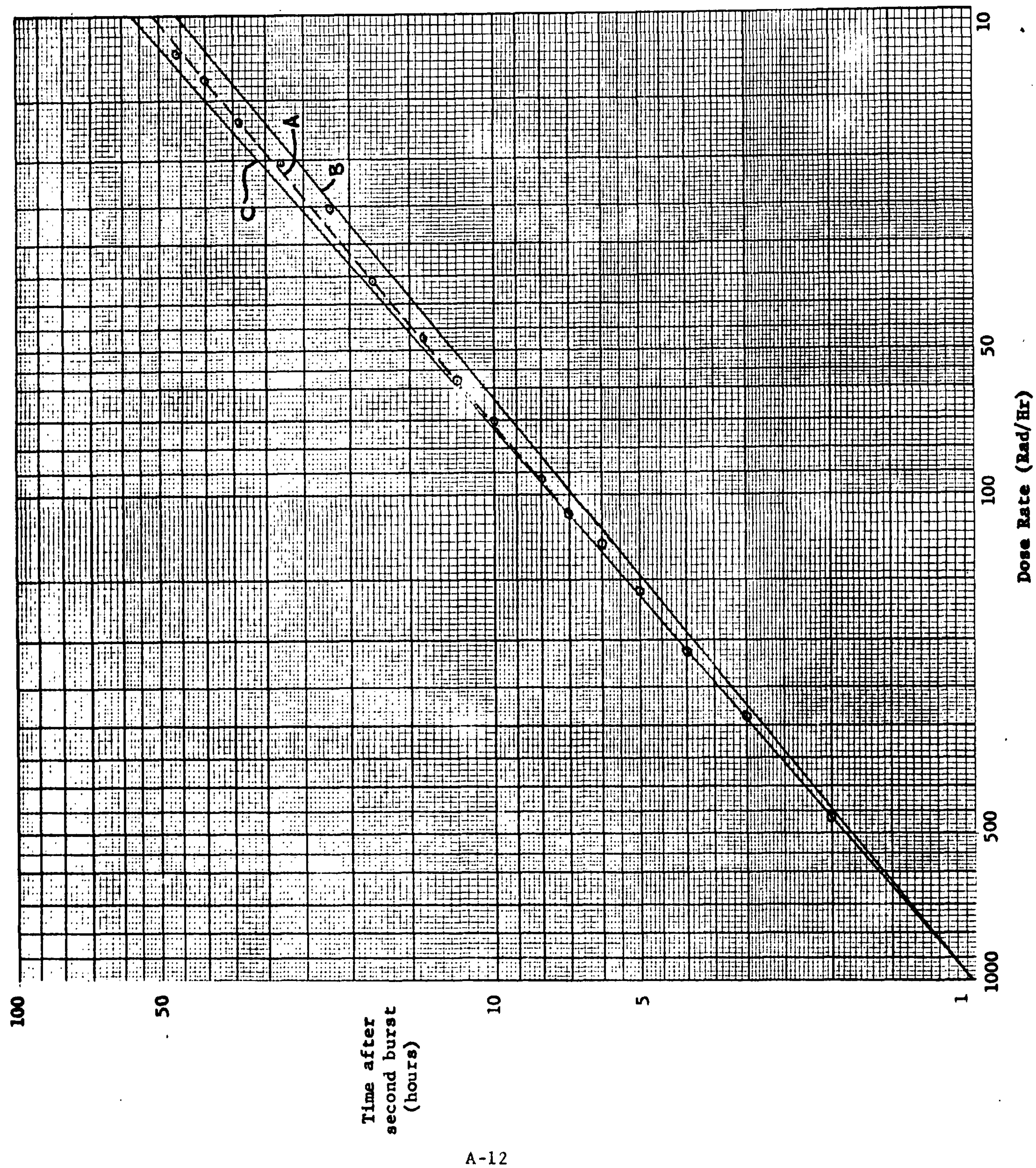


Figure A-6. R_{1X} = 200 rad/hr, R_{1Y} = 1000 rad/hr, 4 Hour Separation

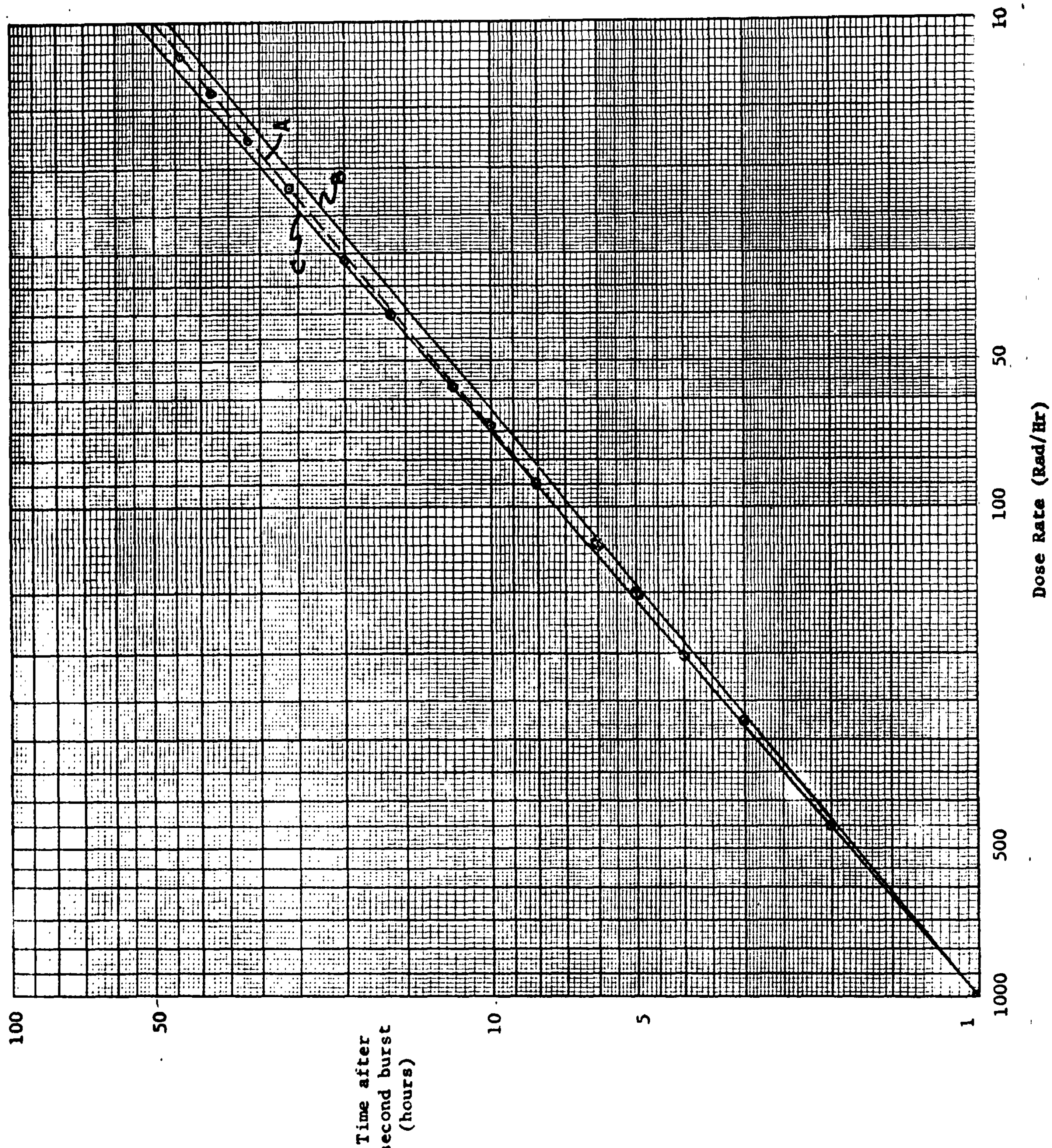


Figure A-7. R_{1X} = 200 rad/hr, R_{1Y} = 1000 rad/hr, 6 Hour Separation

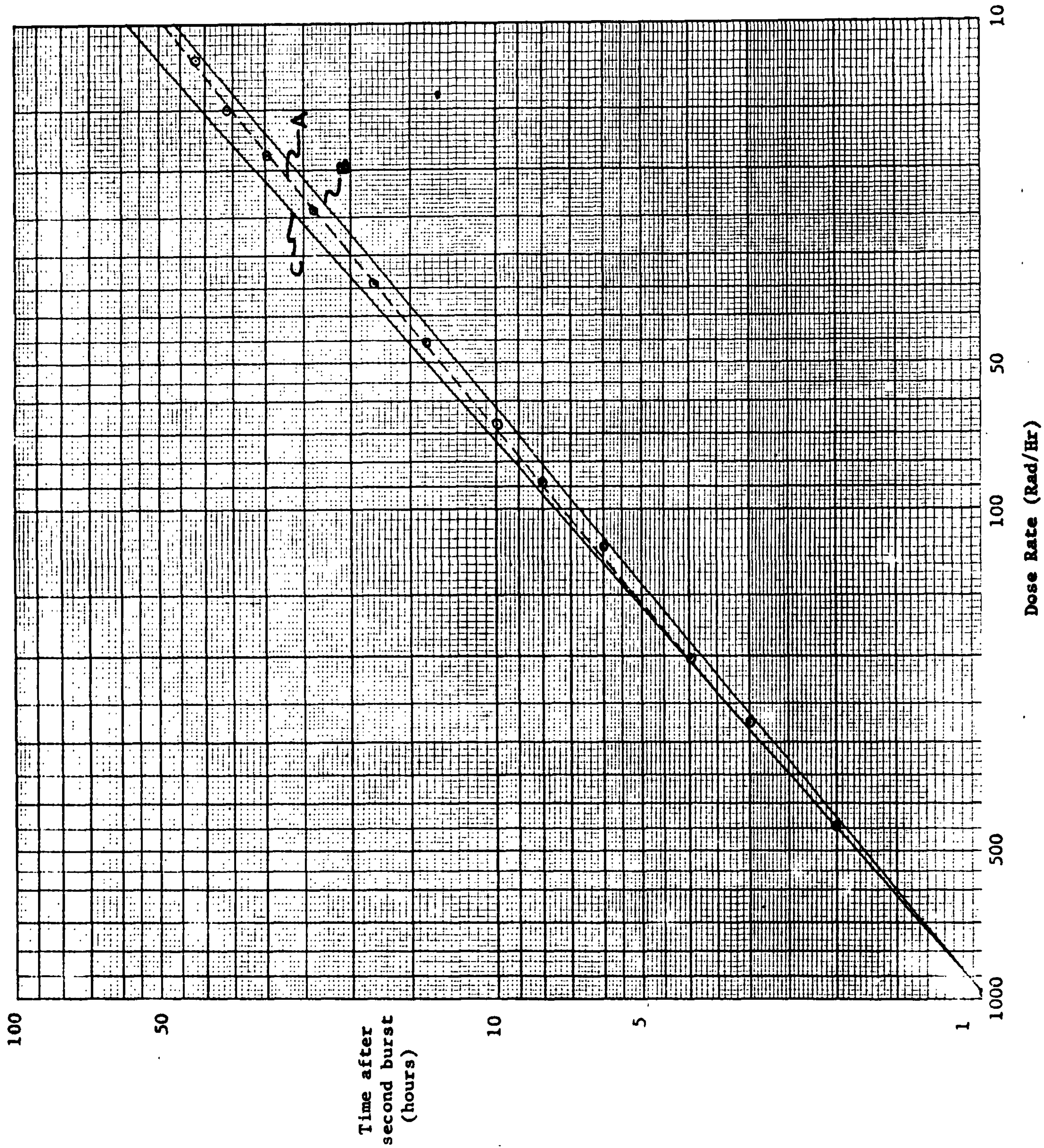


Figure A-8. R_{1X} = 200 rad/hr, R_{1Y} = 1000 rad/hr, 8 Hour Separation

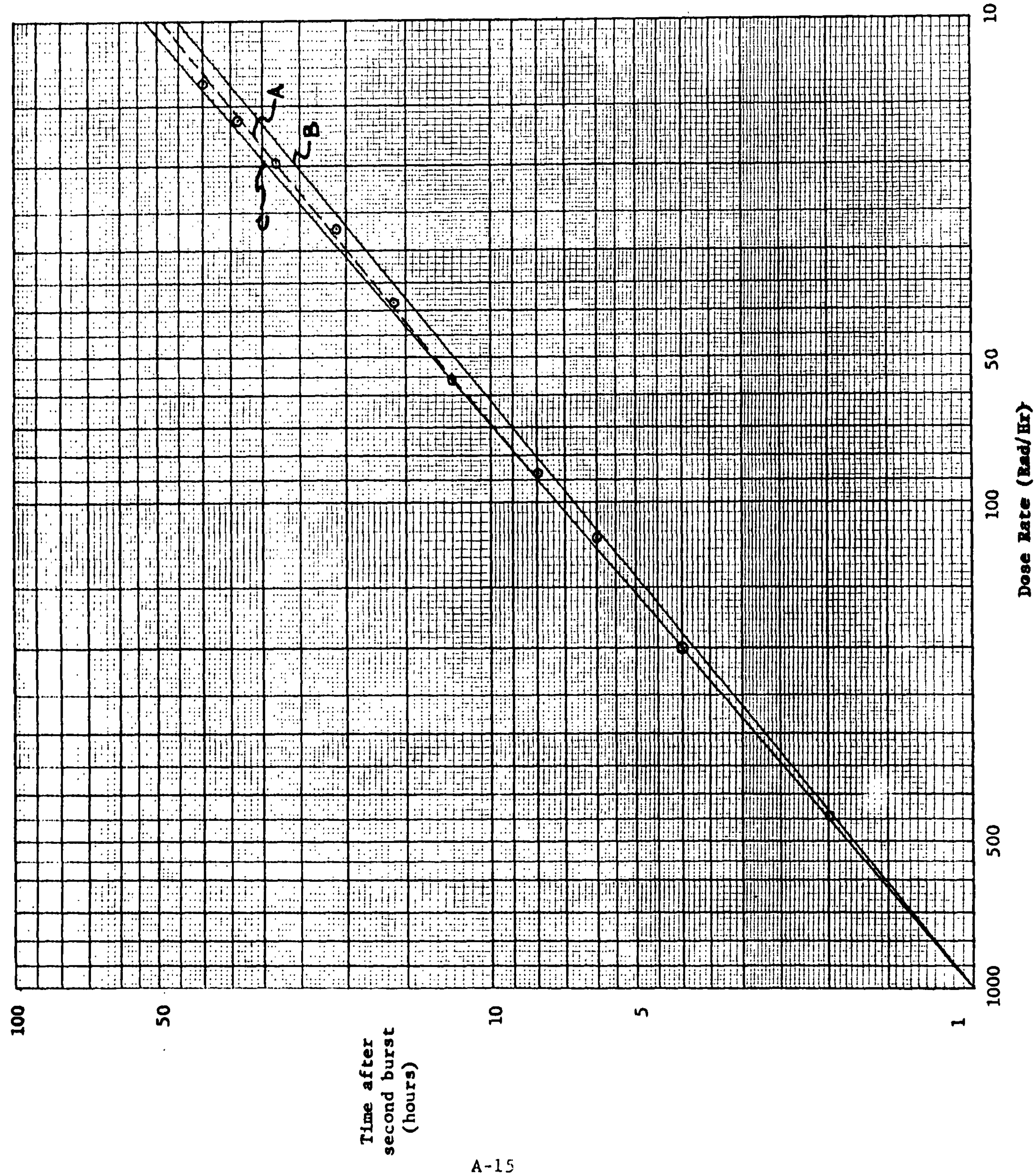


Figure A-9. R_{1X} = 1000 rad/hr, R_{1Y} = 1000 rad/hr, 2 Hour Separation

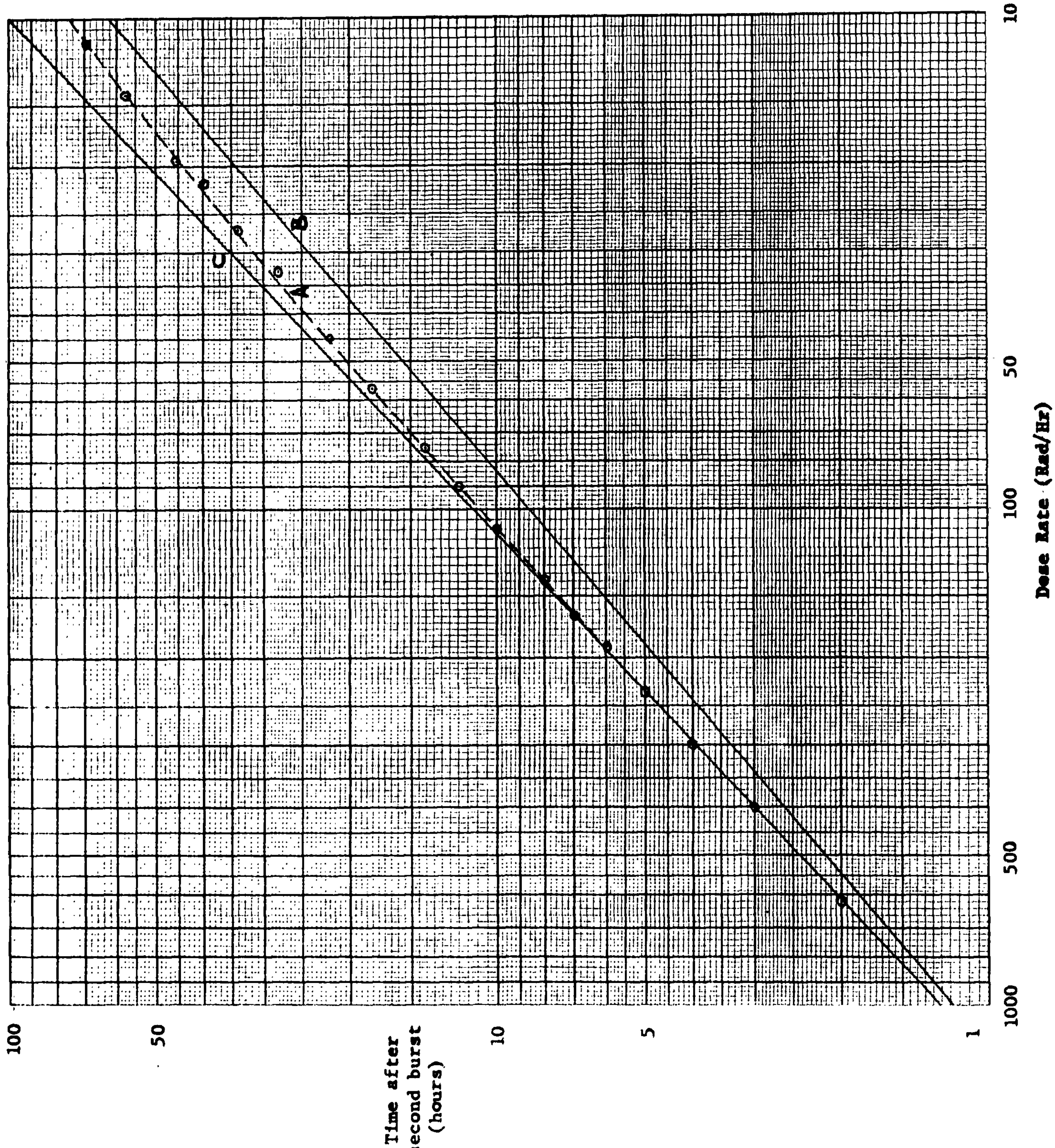


Figure A-10. R_{1X} = 1000 rad/hr, R_{1Y} = 1000 rad/hr, 4 Hour Separation

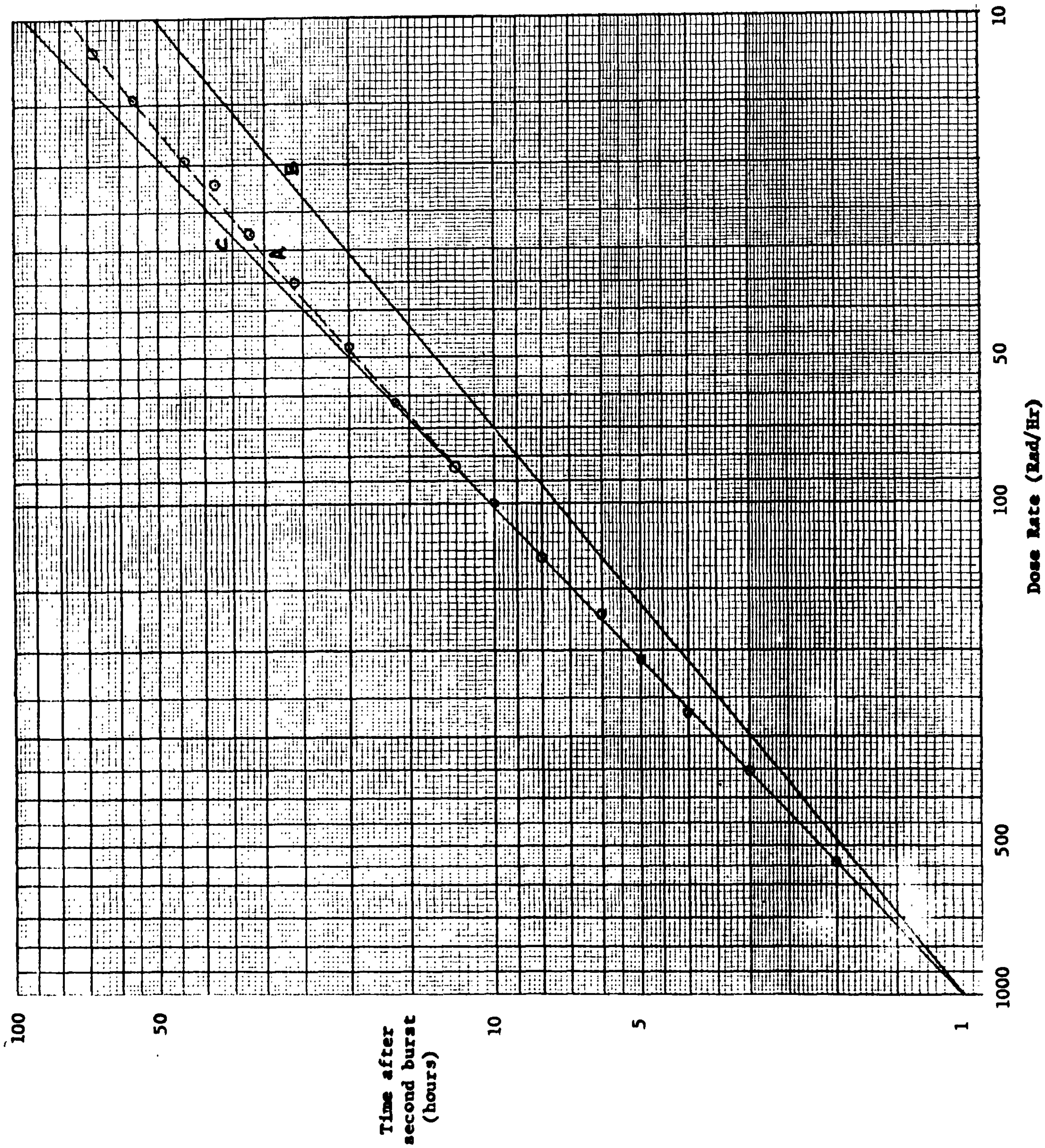


Figure A-11. R_{1X} = 1000 rad/hr, R_{1Y} = 1000 rad/hr, 6 Hour Separation

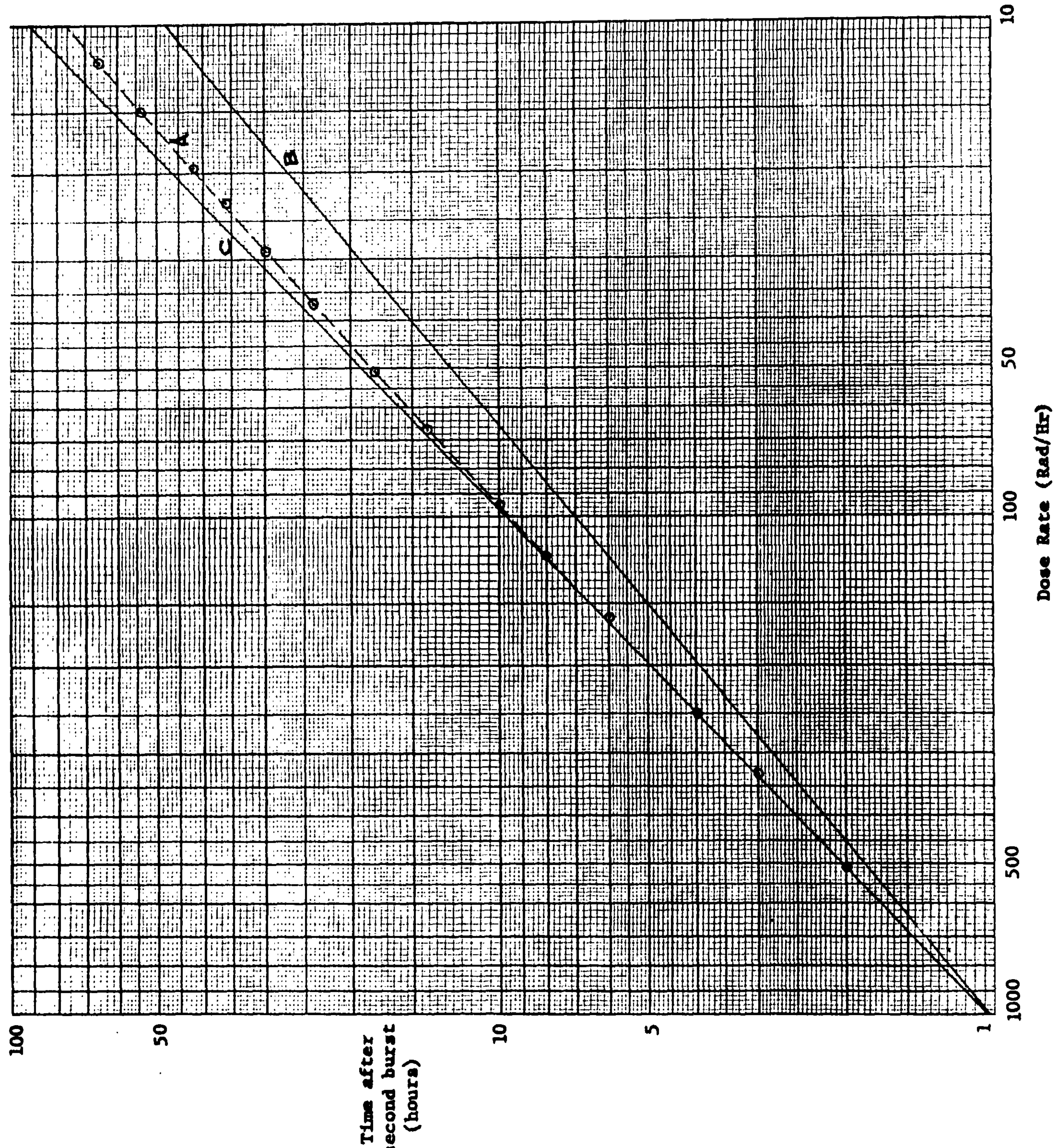


Figure A-12. R_{1X} = 1000 rad/hr, R_{1Y} = 1000 rad/hr, 8 Hour Separation

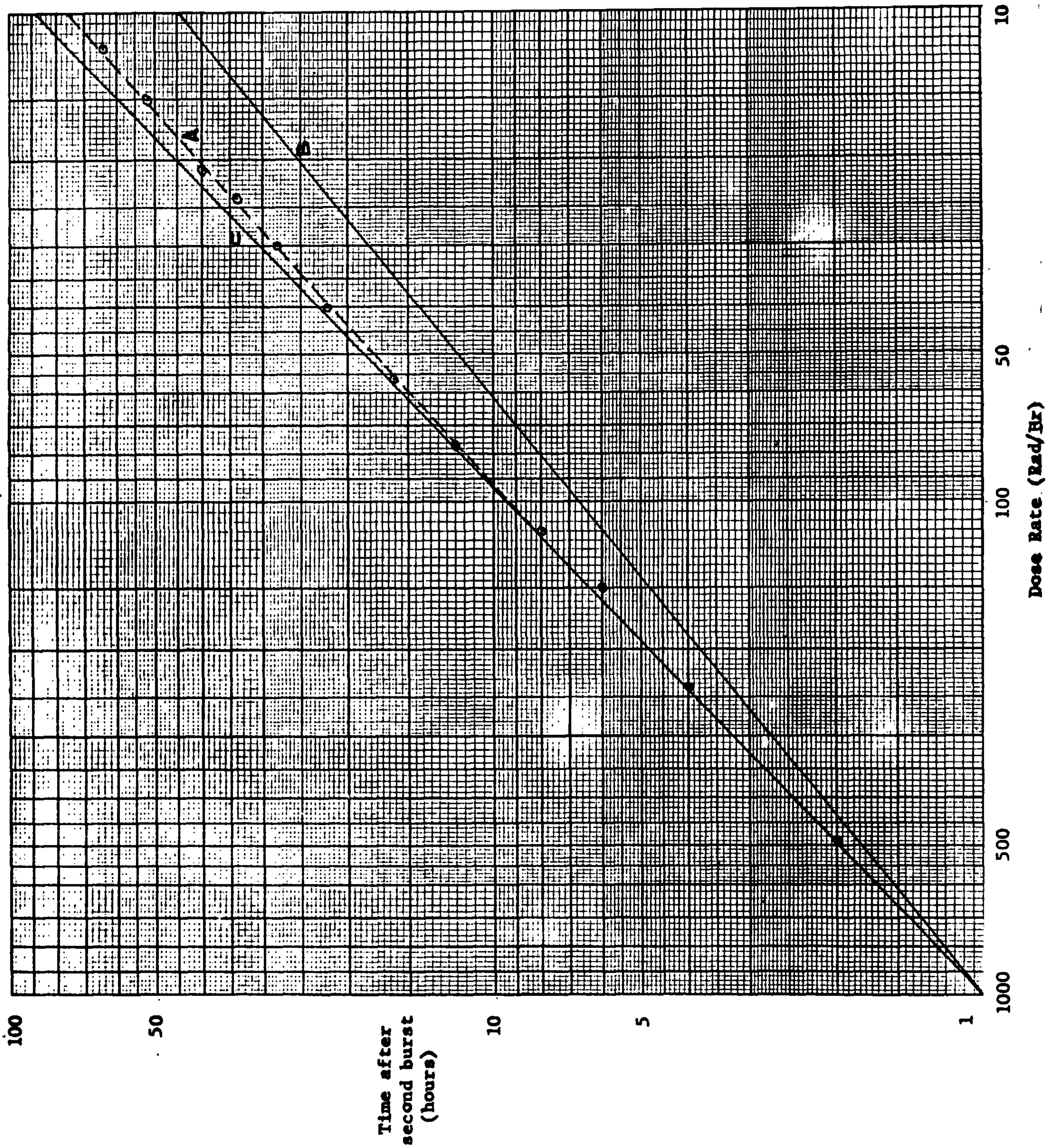


Figure A-13. R_{1X} = 1000 rad/hr, R_{1Y} = 200 rad/hr, 2 Hour Separation

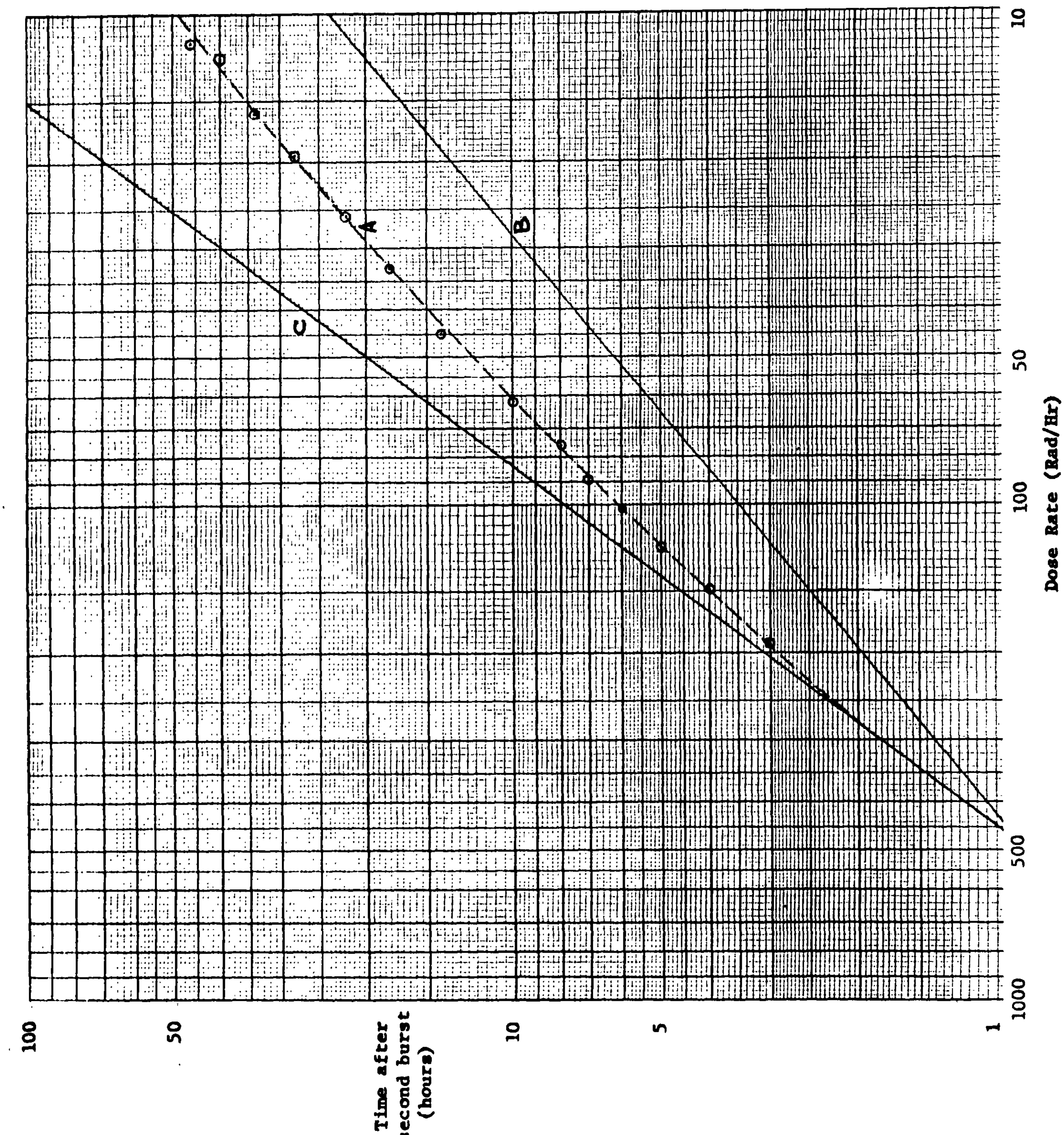


Figure A-14. R_{1X} = 1000 rad/hr, R_{1Y} = 200 rad/hr, 4 Hour Separation

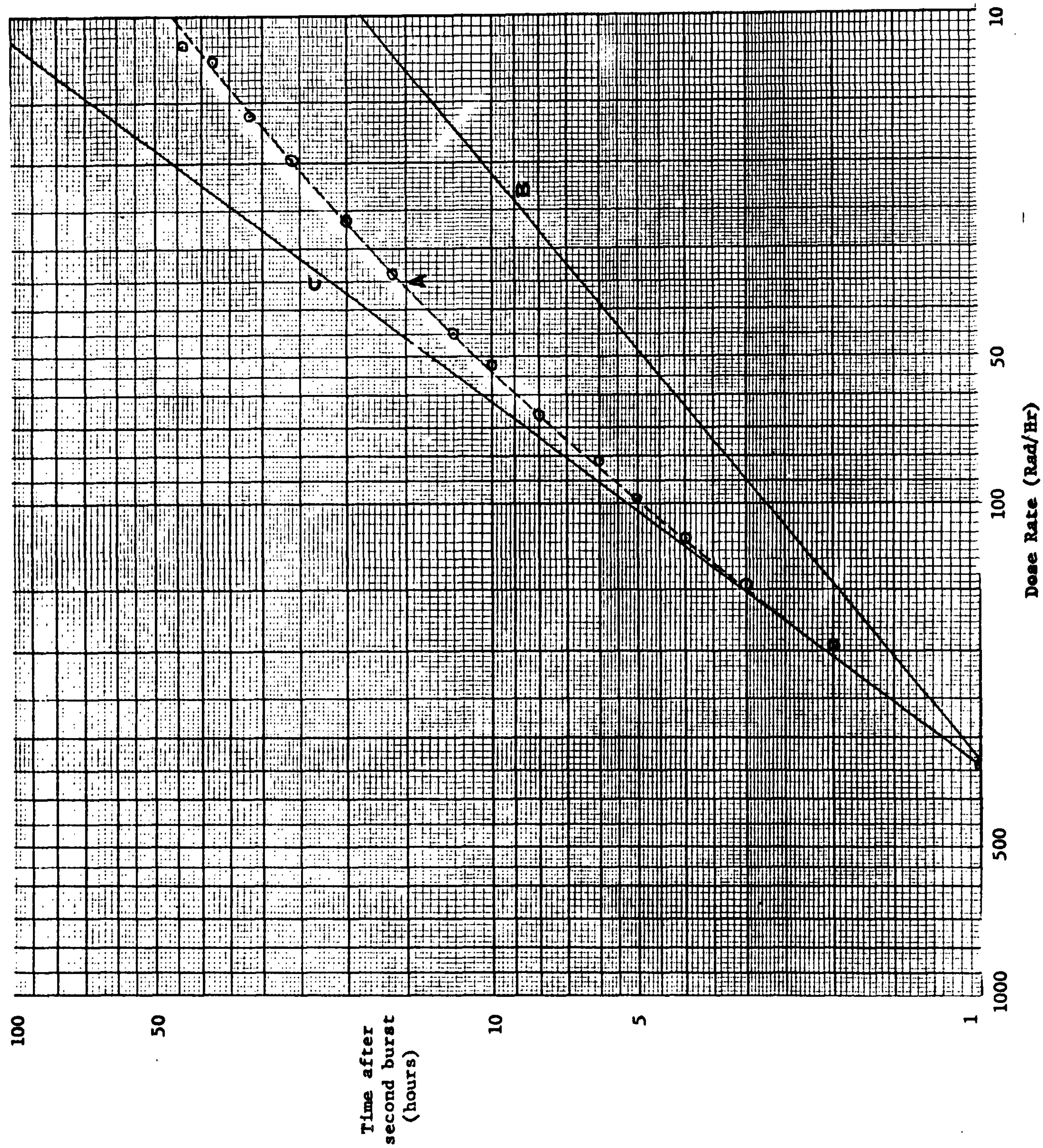


Figure A-15. R_{1X} = 1000 rad/hr, R_{1Y} = 200 rad/hr, 6 Hour Separation

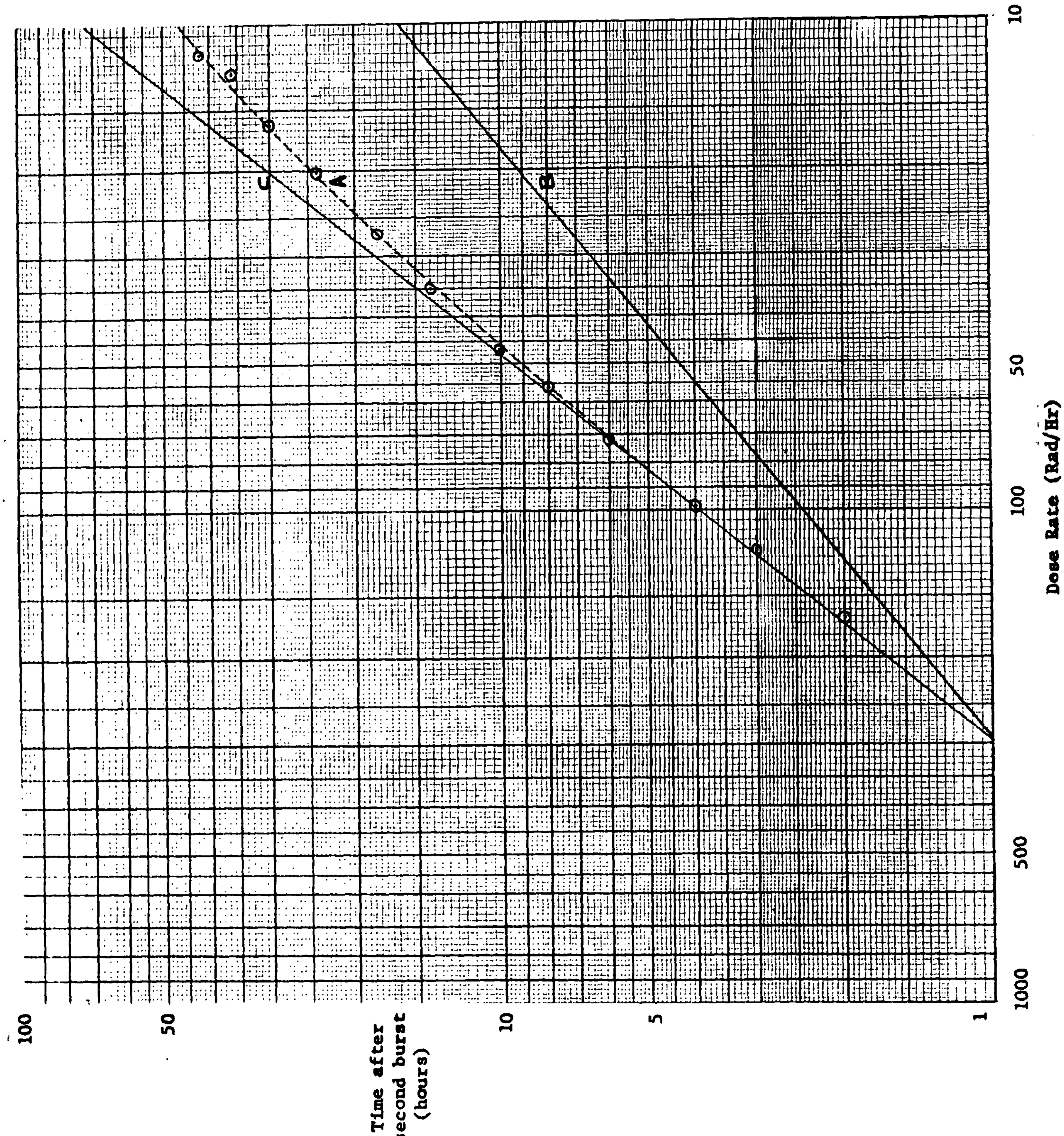


Figure A-16. R_{1X} = 1000 rad/hr, R_{1Y} = 200 rad/hr, 8 Hour Separation

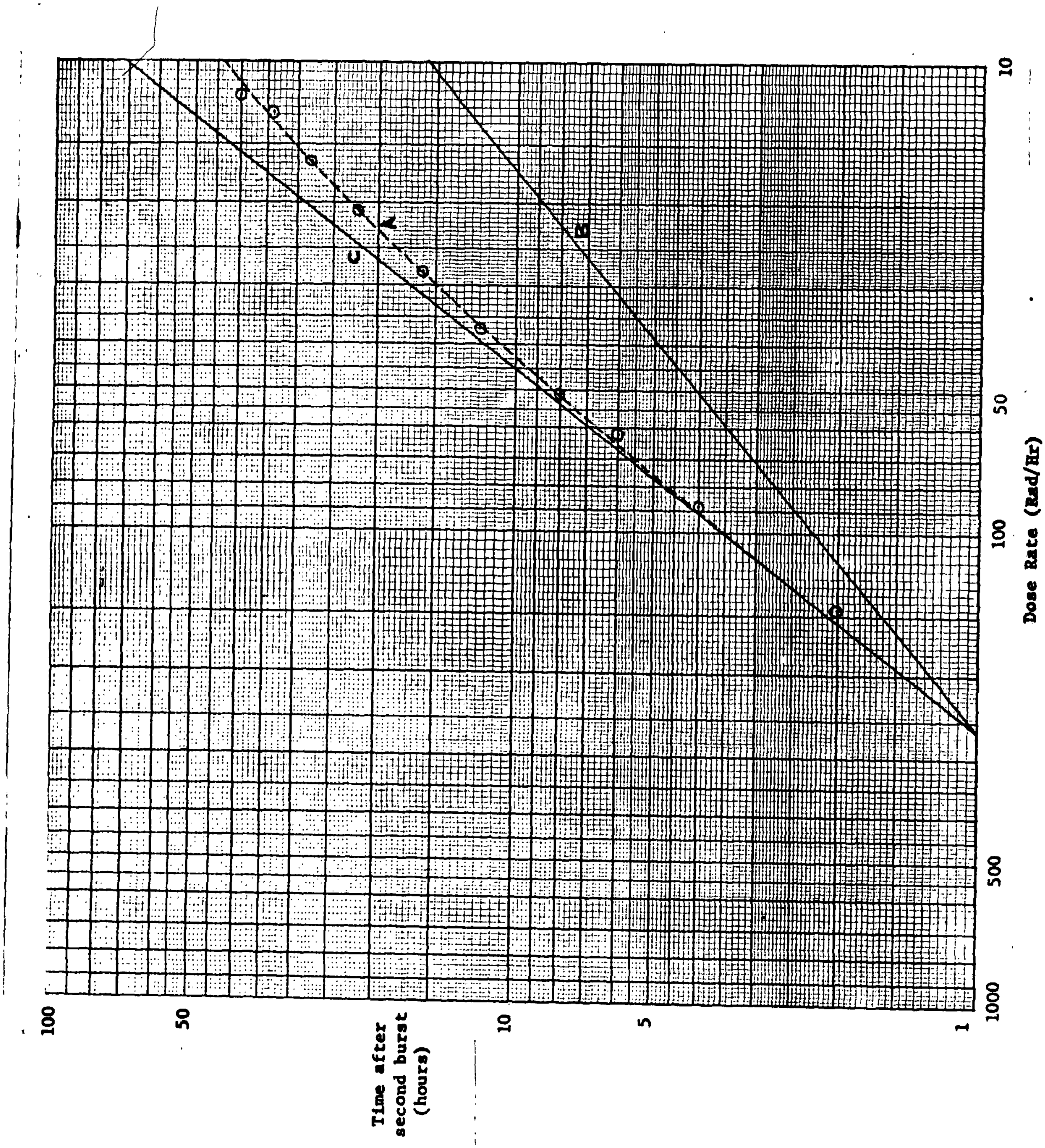


Figure A-17. R_{1X} = 1000 rad/hr, R_{1Y} = 100 rad/hr, 2 Hour Separation

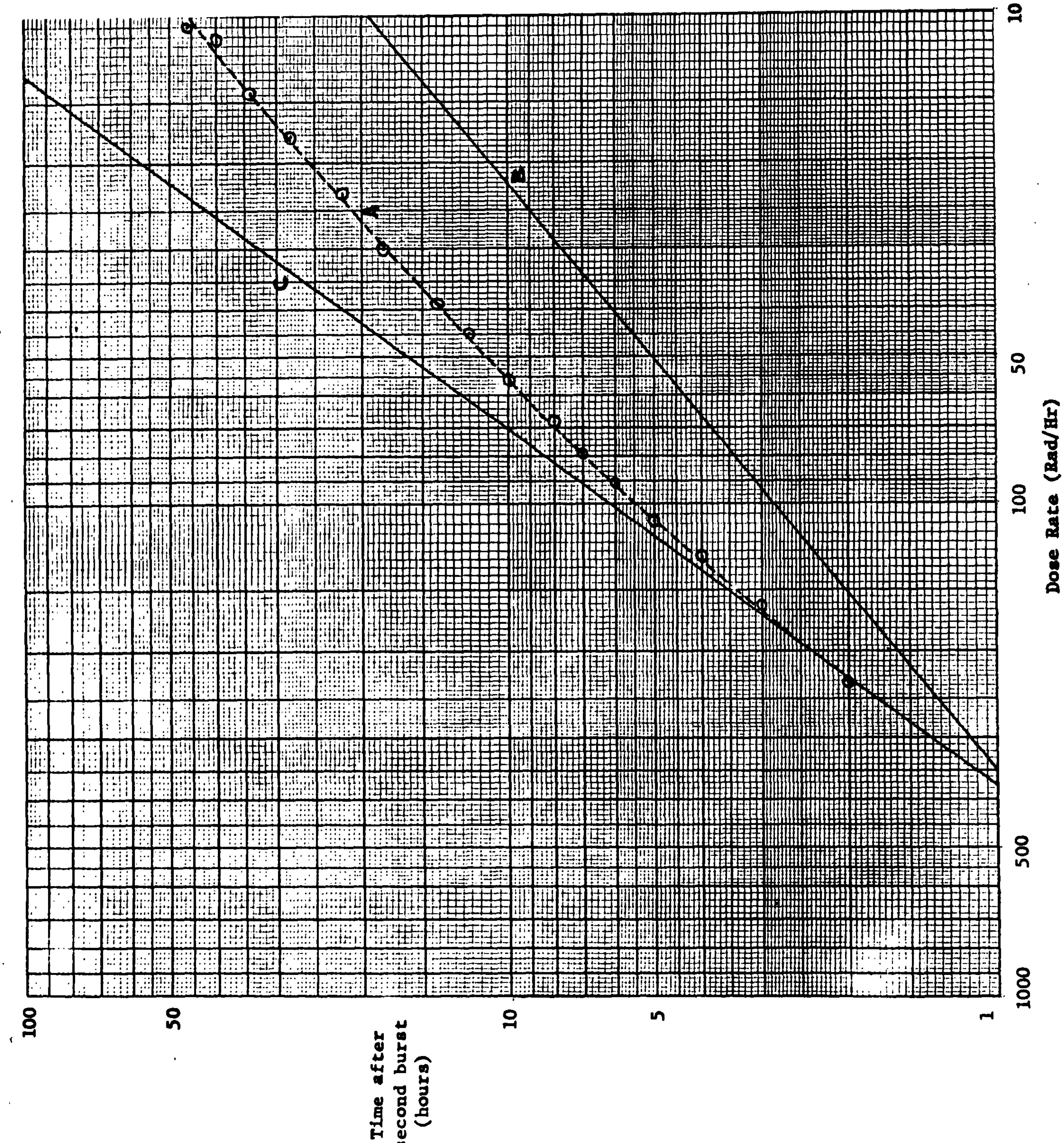


Figure A-18. R_{1X} = 1000 rad/hr, R_{1Y} = 100 rad/hr, 4 Hour Separation

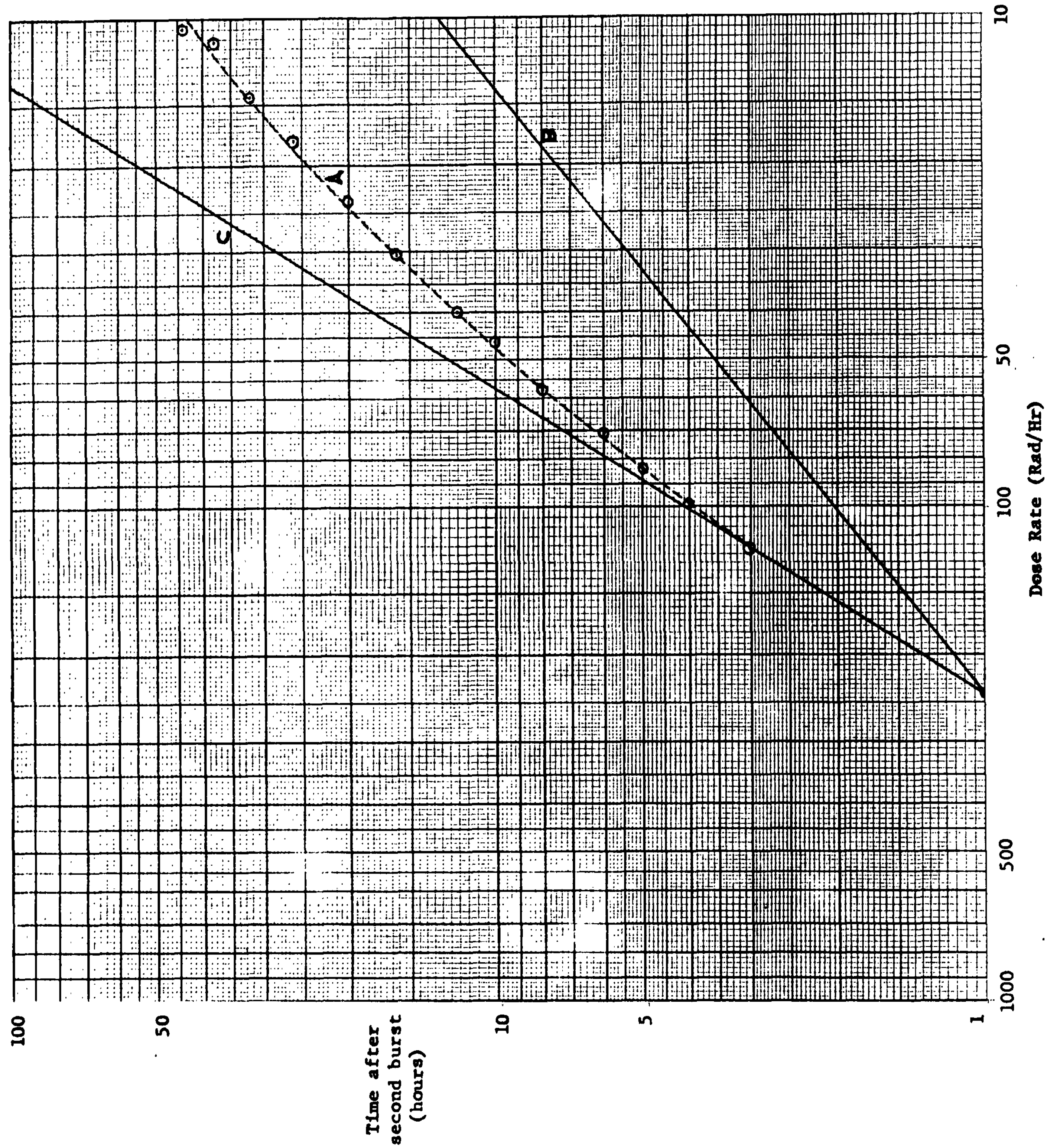


Figure A-19. R_{1X} = 1000 rad/hr, R_{1Y} = 100 rad/hr, 6 Hour Separation

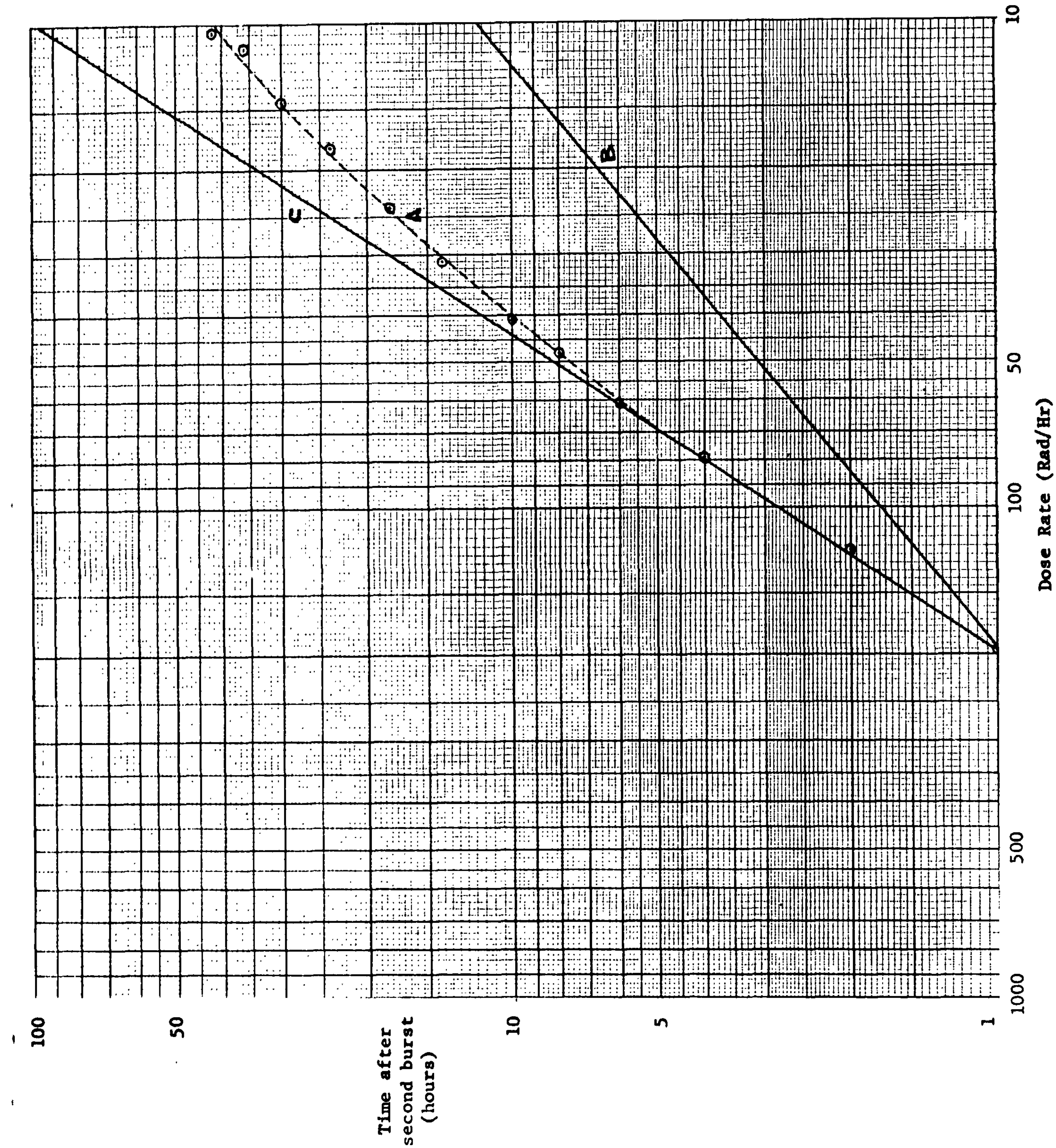
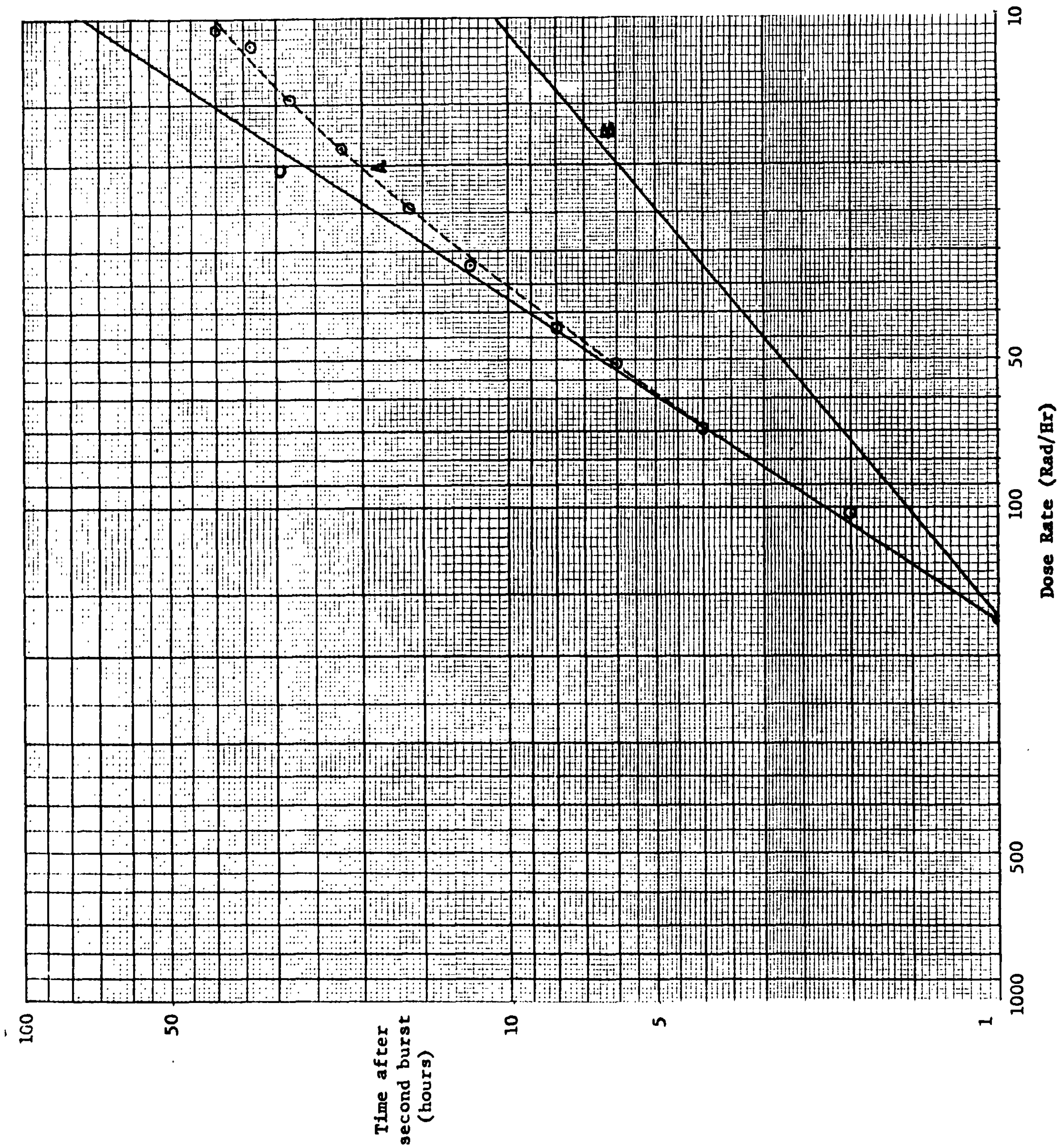


Figure A-20. R_{1X} = 1000 rad/hr, R_{1Y} = 100 rad/hr, 8 Hour Separation



c. The following general conclusions can be drawn from an examination of these graphs:

(1) The errors resulting from either approximation method vary from only a few percent to as high as 80% of the actual future dose rates for these illustrations.

(2) The errors resulting from either approximation method are generally less than 10% when the bulk of the radiation comes from the later contributor.

(3) The error resulting from the use of the extrapolation method (line C) appears to be generally smaller than the error resulting from the use of the combined method (line B).

(4) The extrapolation method (line C) approximately matches the actual future dose rates (line A) in some cases and overestimates the actual dose rates for the balance.

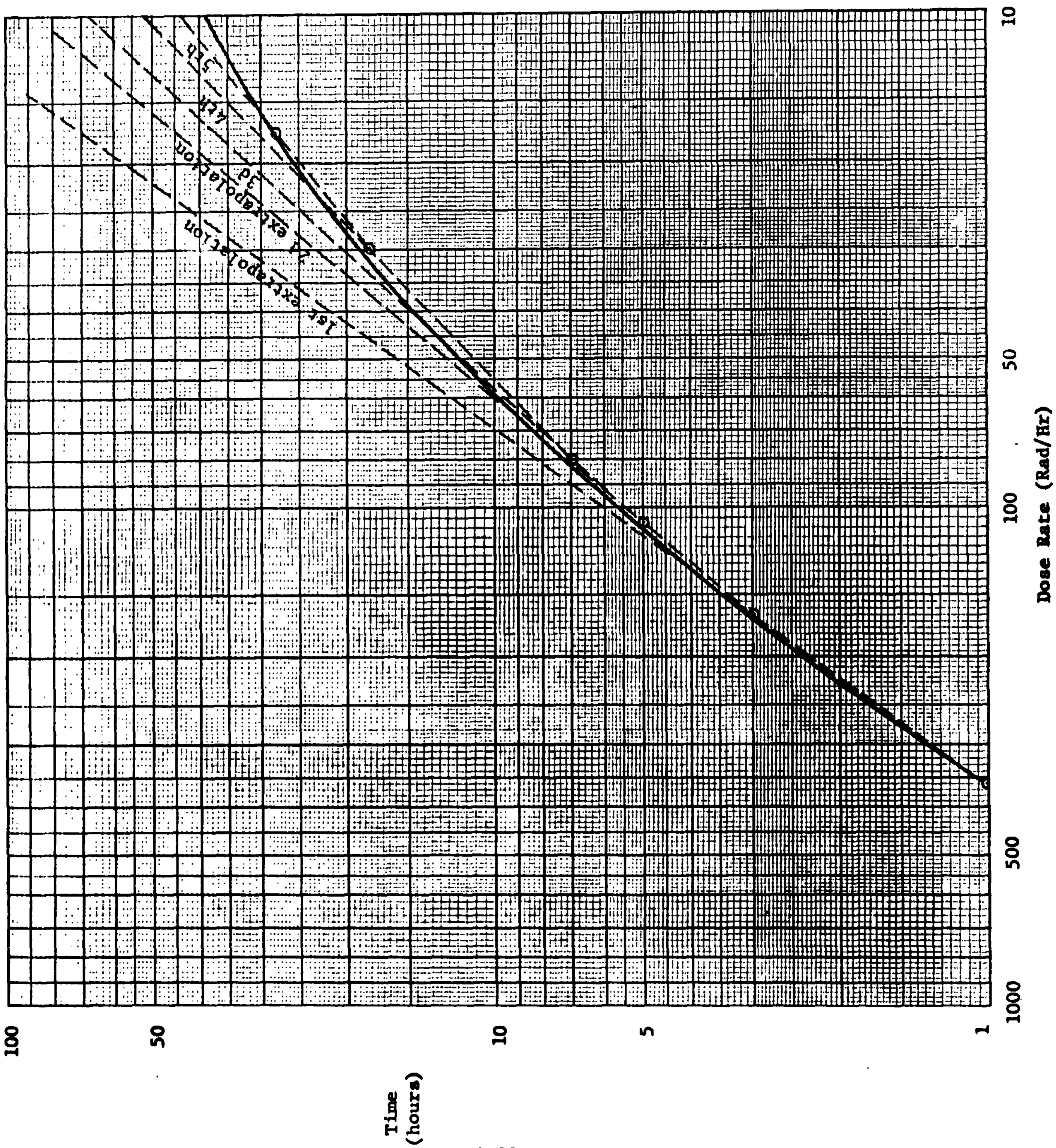
(5) The combined method (line B) consistently underestimates the actual future dose rates (line A).

(6) The errors resulting from either approximation method appear to vary in a regular manner, but it would be necessary to know the relative contributions and/or the time separation between bursts to estimate a correction factor for any time.

(7) The errors between the actual future dose rates (line A) and the combined method prediction (line B) tend to increase with increasing time separation between bursts while the errors associated with the extrapolation method (line C) remain reasonably constant under the same conditions.

10. In paragraphs 8 and 9 above four possible methods of predicting or approximating future dose rates have been presented. The Canadian method, described in paragraph 8a, is exact in its results but is not suitable for field use due to its complexity. The component method, described in paragraph 8b, is simple and exact. However, sufficient information must be available to describe the contribution from the first source before later contributions are deposited. Because this method is exact and the techniques used are already in use and well known, this method should be used whenever possible. The combined method, described in paragraph 9b(1), has two serious drawbacks. In many situations the errors resulting are significant, and seriously underestimate the future hazard. The extrapolation method, described in paragraph 9b(2), requires at least two readings and consist of merely drawing a straight line between the readings on full logarithmic

Figure A-21. Extrapolation method, with periodic revisions.



graph paper. While the errors can be significant with this method, the method consistently overestimates actual future dose rates. The error resulting from this method can be reduced to a great extent by successive revisions. Whenever a new reading is obtained at the location of interest, the prediction line can be redrawn. With each revision the errors will be reduced. Thus, for late times, where the errors are largest, the opportunity to obtain several readings in the interim permits a significant reduction in the resulting error. This method of revision is illustrated in figure A-21 where a series of extrapolations has been plotted, each line using the last two data points available at the time of the revision. It can be readily seen that the error is considerably less for later revisions than for the original prediction.

11. For the above reasons, the following procedure is recommended for field use when predicting fallout decay.

a. When sufficient information is known to permit the separation of the different contributions, the component method, utilizing standard single source procedures, should be used. This method is exact and simple.

b. However, if sufficient information is not available, the extrapolation method from two or more field readings should be used with periodic revisions to the prediction made as subsequent readings are obtained. While this method is not as accurate as the Canadian method, the simplicity of this system in comparison is considered sufficiently important to warrant such a decision. The accuracy of this system is significantly improved if later readings are utilized to revise the prediction. This system has the further advantage that it would be equally valid if the activity from any or all contributors were to decay in a non-standard manner.

12. There still remains the problem of predicting total doses that will be received from a mixed fallout field. This prediction can be made in only one manner at this time. Since the dose received over any period is merely the integral of the dose rate for that period, a graphical integration can be made of any plot predicting the dose rate over the time of interest. The techniques used in this method have been in use for a number of years and are contained in detail in Reference 8.

SECTION III - FALLOUT PREDICTION

13. The overlapping of fallout patterns will also have a considerable effect on the problem of fallout prediction. As with decay and total dose calculations, little serious consideration has been given

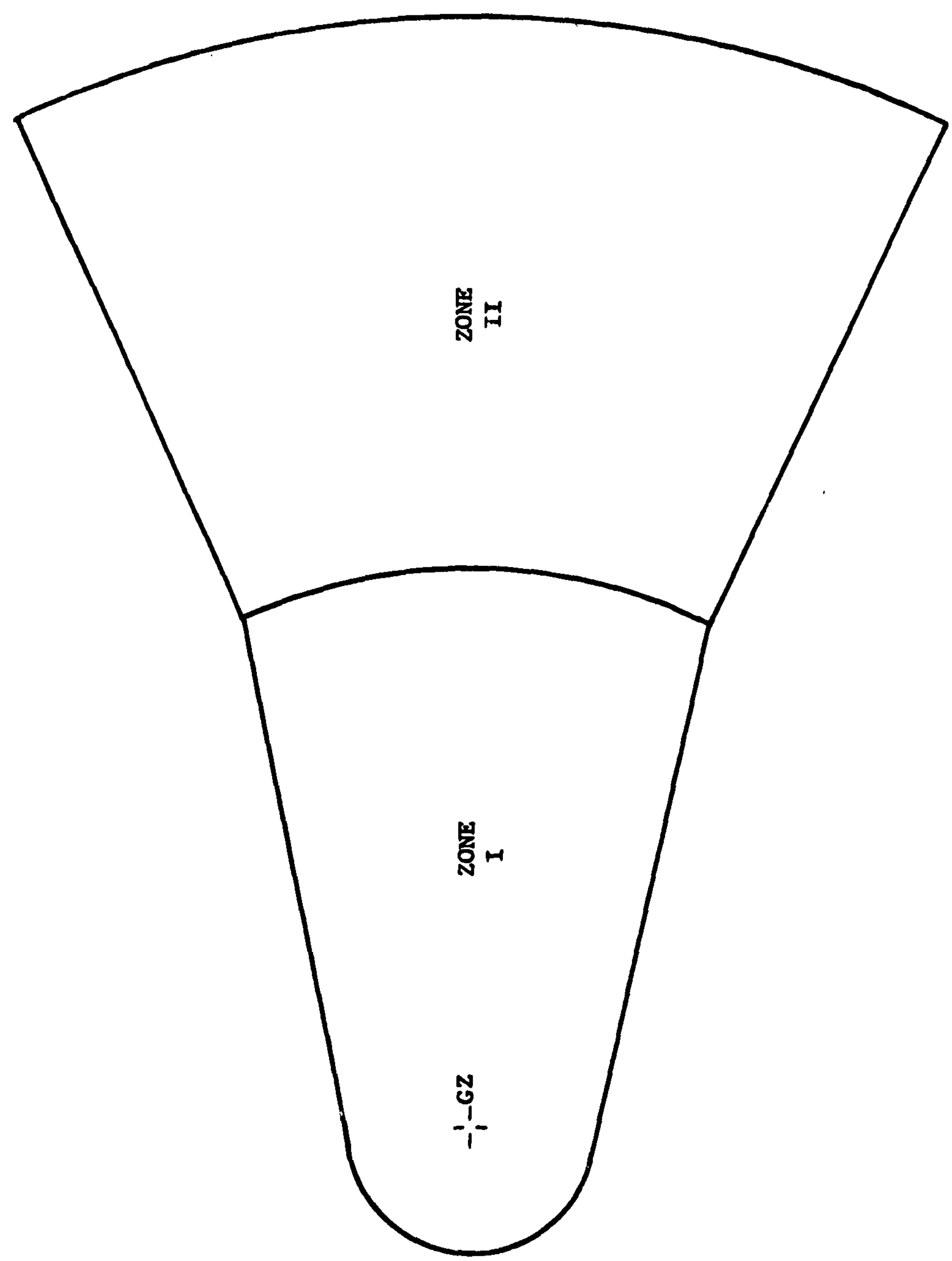
to the prediction problem associated with fallout in one area from more than one burst.

14. The state of the art does not now permit highly accurate, reliable fallout predictions to be made, even for fallout from a single nuclear burst. This is an extremely complex area of nuclear weapon effects research. The deposition of fallout from a nuclear weapon is dependent on many factors which in themselves are not well understood. These factors include such things as the mechanisms of fallout particle formation, atmospheric transport of particles, fallout particle characteristics, statistical climatological variations, and other similar considerations. As a result of the complexity of this field, many fallout prediction methods have been developed over the years. These prediction systems vary considerably in their complexity. At one end of the spectrum are sophisticated computer systems which attempt to delineate exact fallout contours. Many hours of computer time are required to complete the prediction for a single event with some of these systems. At the other end of the spectrum are simple manual prediction systems which attempt only to indicate the probable direction in which the bulk of the fallout will be deposited. Because of the complexities and uncertainties involved, most of the effort in this area has been devoted to the solution of the fallout prediction problem for single bursts only.

15. The requirements for simplicity and speed in a field prediction system for Army use have dictated that one of the less sophisticated prediction systems be adopted for this use. The current Army fallout prediction system is described in reference 6. This system predicts only a warning sector, divided into a primary and a secondary hazard zone. These hazard zones are defined as those areas within which exposed, unprotected personnel <u>may</u> receive militarily significant total doses of nuclear radiation in the first several hours <u>after</u> actual arrival of fallout. Zone I will normally include those areas where doses greater than 100 rad may be received in less than four hours after fallout arrival. Zone II should include all other significant fallout areas where doses less than 100 rad in the first four hours after fallout arrival may be accrued. Outside these two zones exposed, unprotected personnel should not receive doses greater than 20 rad in the first six hours after fallout arrival. A typical prediction plot is shown in figure A-22. The areas which actually receive the above doses are expected to be smaller than the corresponding zones. That is, the zones are merely areas which will include the hazard levels associated with them with a high degree of certainty. Thus it can be seen that one should not merely add the expected doses associated with particular hazard zones when these zones overlap.

16. There are four possible combinations of hazard zones which are of interest. These are the cases where a Zone I area

Figure A-22. Typical fallout prediction



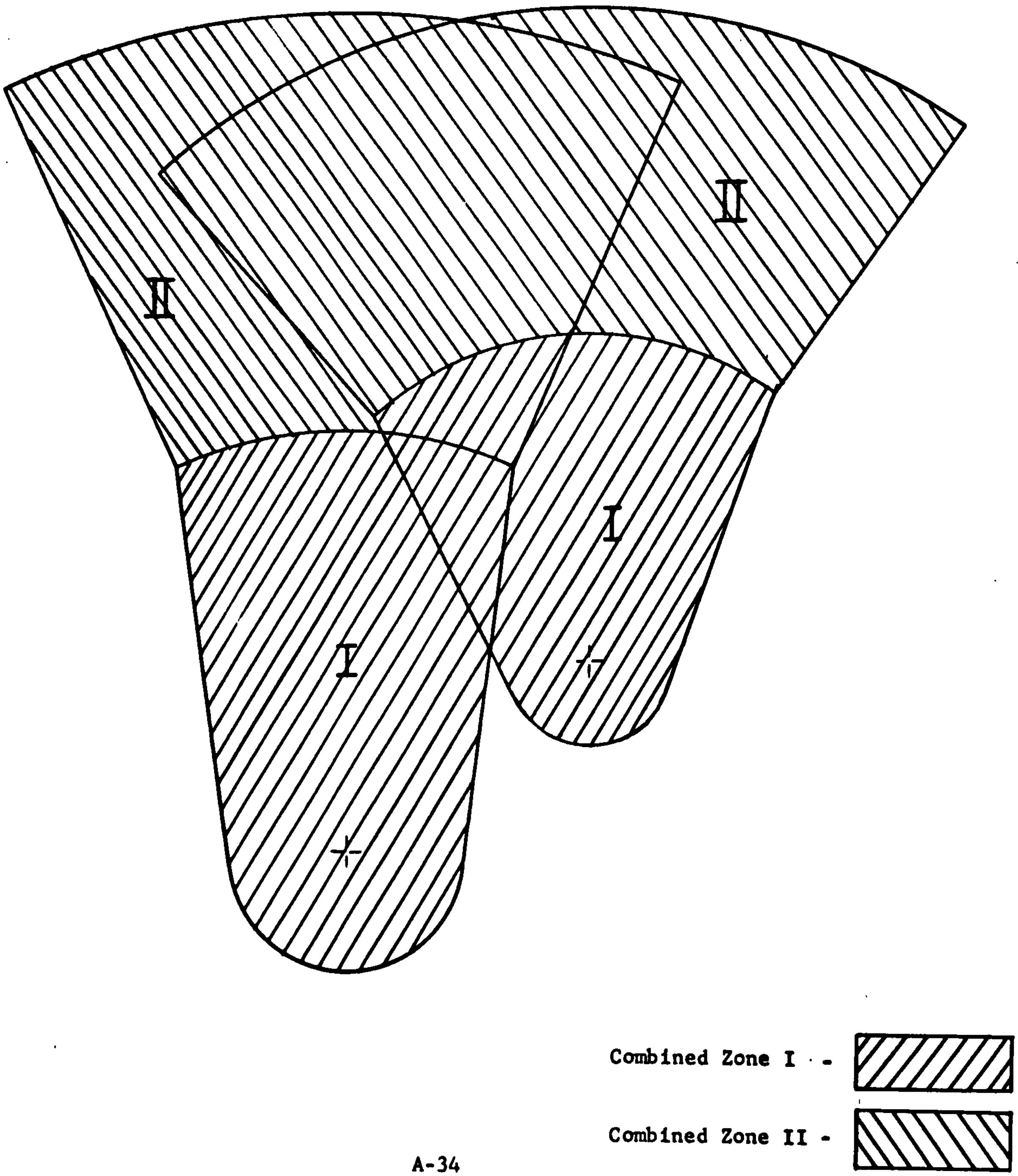
overlaps another Zone I area, where a Zone I area overlaps a Zone II area, where a Zone II area overlaps another Zone II area, and where either a Zone I or a Zone II area overlaps an area just outside the hazard areas of another prediction.

a. When two areas designated as Zone I overlap, the actual dose received within the area of overlap could range from zero to infinity. The definition of Zone I merely states that doses greater than 100 rad can be incurred within the specified time limit. Since there is no upper limit to this zone, any additional contamination in this zone would not raise the hazard designation. Therefore, areas of overlap of this type could still be designated Zone I and satisfy the definition of such a zone. No further action would be indicated for an area of overlapping Zone I's than would be appropriate for an isolated Zone I.

b. For the same reasons stated in the preceding paragraph, an area of overlap involving a Zone I and a Zone II should be designated as Zone I.

c. The case where an area designated as Zone II in one prediction overlaps a similarly designated area from another prediction is somewhat different. Because there exists an upper limit to the dose that can be incurred in Zone II, there would exist a corresponding upper limit to an area of overlap. Zone II is designated as an area where less than 100 rad would be incurred by unprotected personnel during a specified time. Thus, for an area of overlap, the maximum total dose that would be expected would be 200 rad in the same time (four hours). The lower limit would still be zero as in the previous case. Any portion of the area of overlap in which the accrued dose exceeded 100 rad in four hours would no longer meet the necessary qualifications associated with Zone II. A good indication of the probability of occurrence of areas where doses between 100 rad and 200 rad would be observed would be the fraction of Zone II which would produce doses in excess of 50 rad in four hours. The measured fallout patterns from all known surface or near surface bursts with yields greater than 0.1 KT were examined in conjunction with the prediction which would be made for the conditions of each detonation. Actual yields of the shots used varied from about 0.5 KT to several MT. However, the available data are grouped into two general categories, a few KT or lower, and several hundred KT or higher. There are no available patterns of sufficient reliability for the intermediate yield range. That part of the pattern which would produce doses of 50 rad or greater within Zone II of each prediction was then estimated. If 50 rad in four hours covers a significant portion of each Zone II, then the occurrence of doses greater than 100 rad in overlapping areas should be high. Fourteen known patterns were plotted. Of these, in only seven cases did the 50 rad in

Figure A-23. Overlapping fallout predictions.



four hour contour even reach beyond the end of the predicted Zone I. Of the seven cases where the 50 rad contour did extend into the predicted Zone II, four covered less than 10% of Zone II, one covered about 15% and the other two covered about 20%. From these observations it is unlikely that doses significantly greater than 100 rad in four hours would result in areas where one Zone II overlapped a second one. For this reason, it is not considered advisable to raise the hazard expectancy of an area where two Zone II's overlap. Such an increase would unnecessarily degrade the commander's flexibility.

d. On the basis of comparison of known fallout patterns with their associated fallout predictions, the amount of contamination found outside the boundaries of the two hazard zones is negligible. For this reason the designation of a hazard zone should not be changed because of an overlap with the fringe area around a second prediction.

e. From the above discussion it appears that the hazard classification of an area where fallout patterns overlap should be only that of the higher classification involved. That is, an overlap involving a Zone I should be designated Zone I, and an overlap involving nothing more hazardous than Zone II should be designated Zone II. Figure A-23 illustrates a typical prediction for multiple fallout producing bursts. All of the above discussion on fallout prediction is applicable principally to predictions for bursts which occur spaced closely in time. The Army fallout prediction system, and the designated hazard levels, are valid and useful only for a matter of several hours after a burst. It is not meaningful to discuss the overlapping of predictions if more than a few hours separate the bursts. Current doctrine states that the extent of the contamination will be determined as soon as possible through the use of monitoring and survey reports. When several hours separate the bursts, then the measured contamination pattern already on the ground must be considered in conjunction with the fallout prediction for the later burst. There can be no hard and fast rules to guide the prediction in this situation. Only experience and common sense can be used as a guide for this situation.

f. A particular example of overlapping fallout prediction patterns which warrants further discussion is that obtained when the GZ area for the first burst is contained within Zone II of the fallout prediction pattern for the second burst. The immediate area of ground zero of the first burst, indicated by the circle in Figure A-24, may contribute large amounts of radiation at H + 12 to H + 24 hours. If the dose rate at the first burst's circle is 3000 rad/hr at H + 1 hours, there will remain a dose rate of approximately 75 rad/hr at H + 24 hours. Thus, the indicated Zone I area from the first burst would still be considered a Zone I area, as only a very small contribution from the second burst would be required to boost the combined dose rate to over 80 rad/hr.

Figure A-24. Multiple prediction pattern for two bursts where GZ of first burst is in Zone II of the second burst.

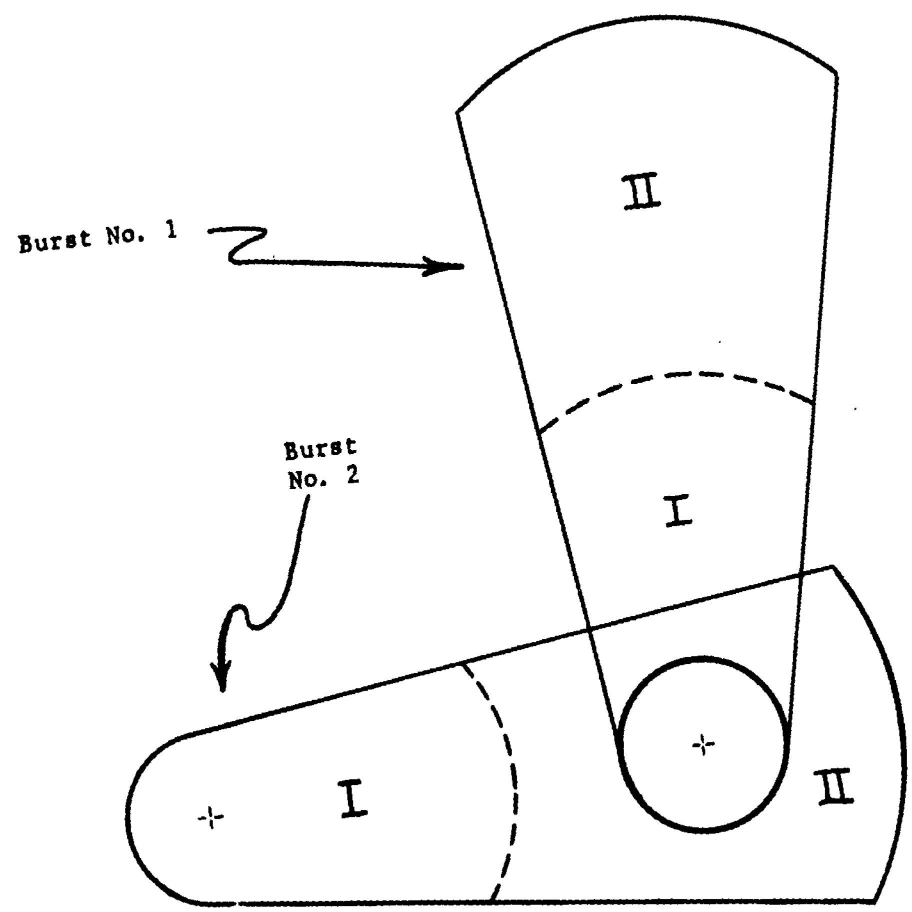
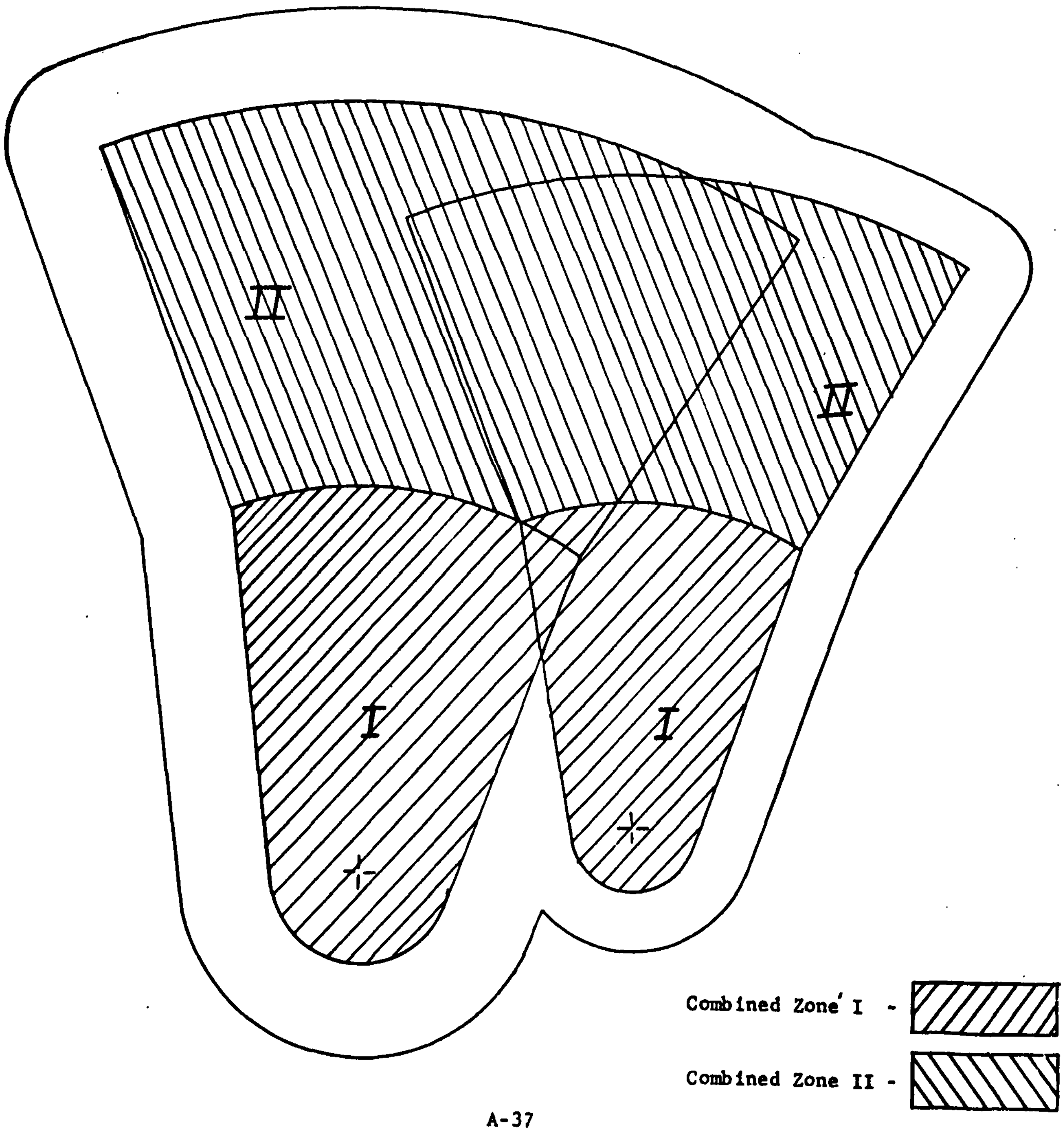


Figure A-25. Multiple prediction pattern for deliberate use of friendly bursts to produce fallout.



g. Known fallout patterns for burst whose yield was less than 0.1 KT were not used in the above considerations as the current Army fallout prediction system cannot be used for such yields. The present lower limit for the system is 0.1 KT. The current limitation is not particularly significant as the fallout from such bursts is limited in area and is deposited so quickly that prediction is of only marginal benefit.

h. Current doctrine on the deliberate use of fallout as an offensive weapon calls for the addition of a buffer distance around the pre-shot prediction for friendly delivered weapons used for this purpose. There is no requirement to modify this technique when a possibility of overlapping predictions exists. This buffer distance is used merely to establish a troop safety distance for friendly personnel, and would be utilized in exactly the same manner with multiple bursts. For the reasons stated in paragraph 16d above, it will not be necessary to assign a hazard designation to areas where buffer zones overlap. Because the current prediction system is not sufficiently accurate to permit commanders to make operational movements on the basis of prediction alone, current nuclear defense measures should be employed when exploiting through an area subjected to fallout from several weapons as would be employed for individual bursts. Figure A-25 illustrates a typical prediction for multiple friendly surface bursts employed to produce fallout.

17. Reference 7 has established the requirements for an improved Army fallout prediction system. These requirements have been coordinated with appropriate combat development agencies and approved by the U. S. Army Combat Developments Command as the best statement of the Army's requirements in the field of nuclear weapons effects research. Many military and civilian agencies are engaged in fallout research with much of the work devoted to the improvement of fallout prediction techniques. Increased knowledge in this area, in conjunction with improvements in associated fields such as meteorology and computer technology, should result in the development for the Army of a prediction system which is capable of satisfying the established requirements. Such a system could, with little difficulty, include a capability to consolidate into a single prediction inputs from several contaminating events. When detailed characteristics for an improved prediction system are formulated, such a capability should be included.

SAMPLE PROBLEM - CANADIAN METHOD

The problem below will illustrate the method of predicting future dose rates as described in reference 5 for the multiple burst situation.

Example: In an area where fallout is complete, the following set of dose rate readings has been recorded starting at some arbitrary time, 0.

TIME (HOURS)	0	1	2	3	4	5	6
DOSE RATE (RAD/HR)	369	275	217	182	155	134	118

Predict the dose rate in this area for 24 and 48 hours after the time of the first reading.

Solution:

Step 1. Plot the dose rates recorded against the time of measurement and construct a smooth curve through the data points. (Figure 1-A-1.)

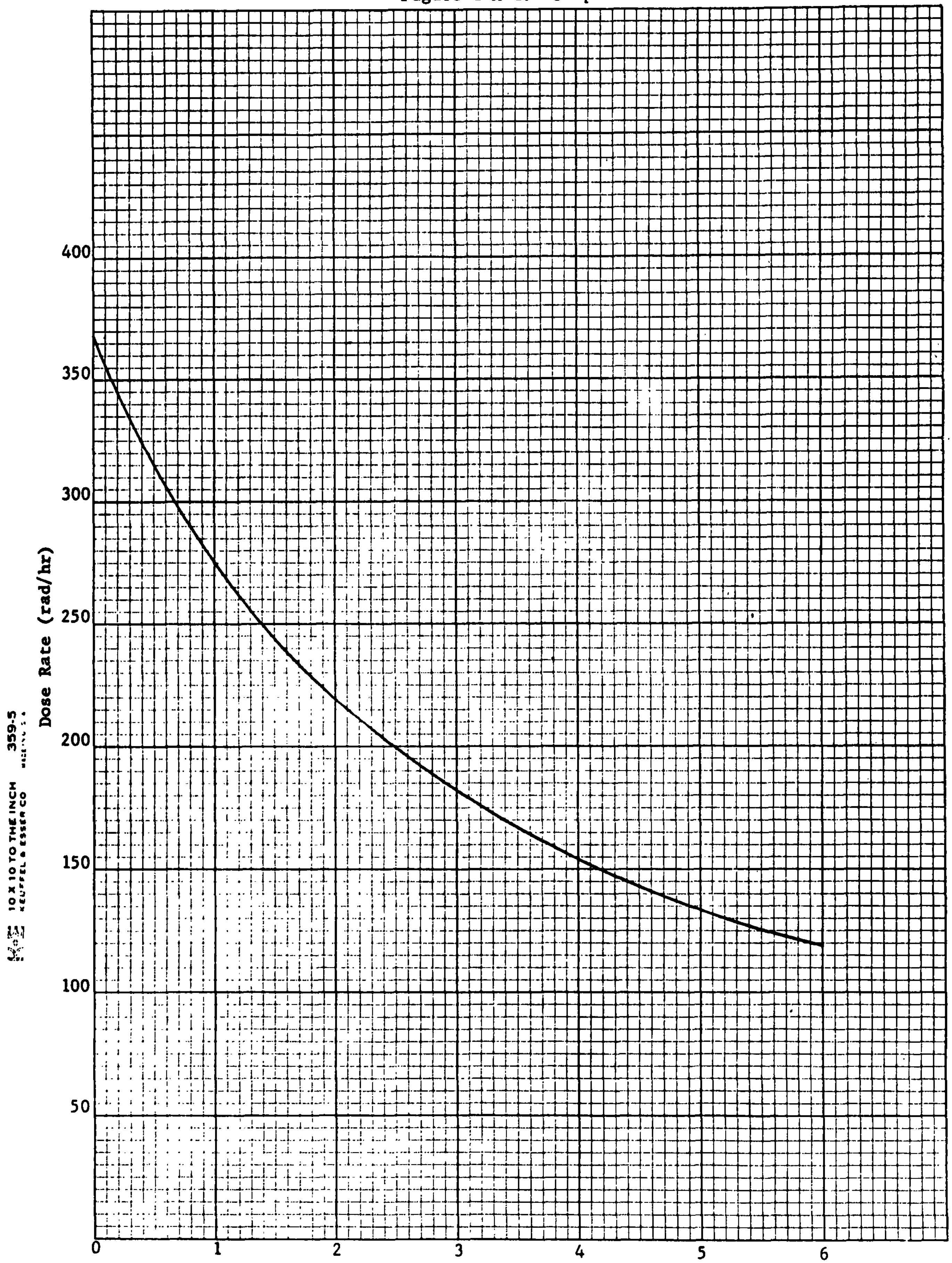
Step 2. Using the smoothed values of radiation intensity obtained in step 1, plot a "characteristic curve" by expressing the intensity values as a percentage of their value two hours previously and plotting linearly against time. (Figure 1-A-2.)

For example - at 2 hours:

$$\frac{R_2}{R_o} \times 100 = \frac{217}{369} \times 100 = 58.9\%$$

Step 3. Compare the plot of the "characteristic curve" drawn in step 2 with the theoretical curves for the t^{-n} decay law, for values of n from 0.8 to 1.4 (figure 1-A-3) with corresponding horizontal lines over each other. Move the plots horizontally (never vertically) with respect to each other until the best fit is obtained between the "characteristic curve" of the plot and one of the theoretical curves of the overlay. Figure 1-A-4 illustrates the best match for the characteristic curve drawn in step 2.

Figure 1-A-1. Step 1



1-A-2

Figure 1-A-2. Step 2

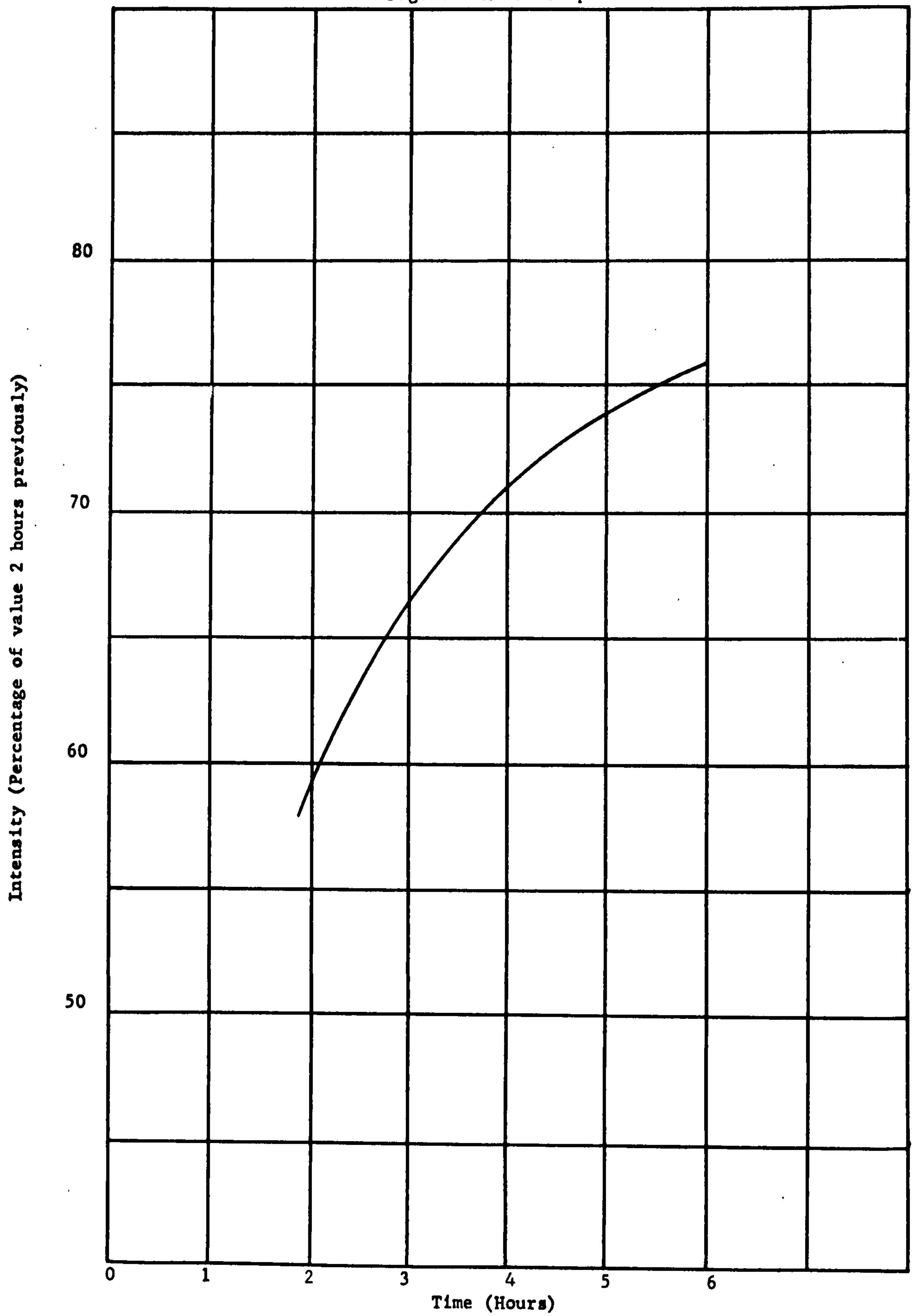


Figure 1-A-3. "Characteristic curves" for decay law t^{-n}

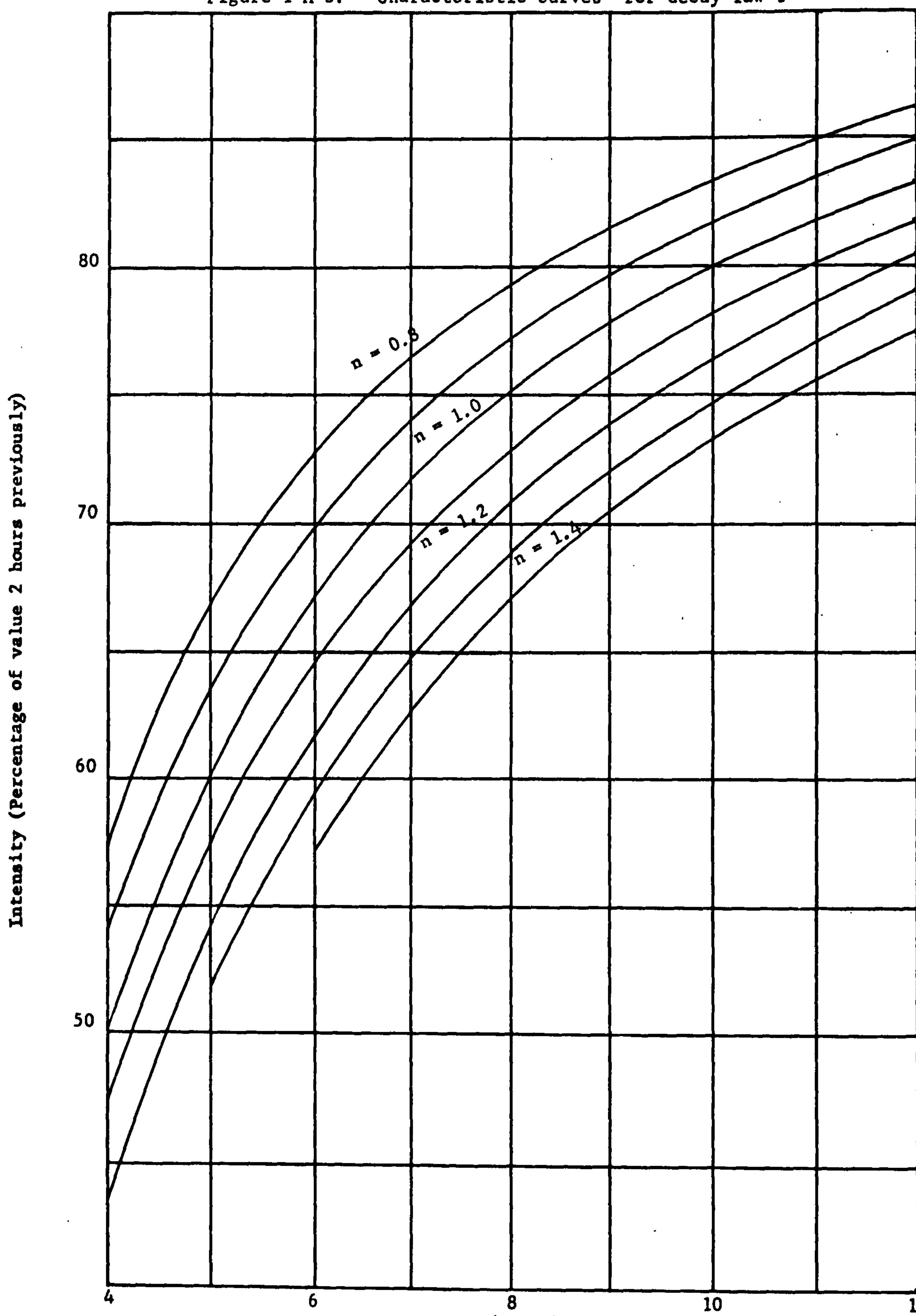
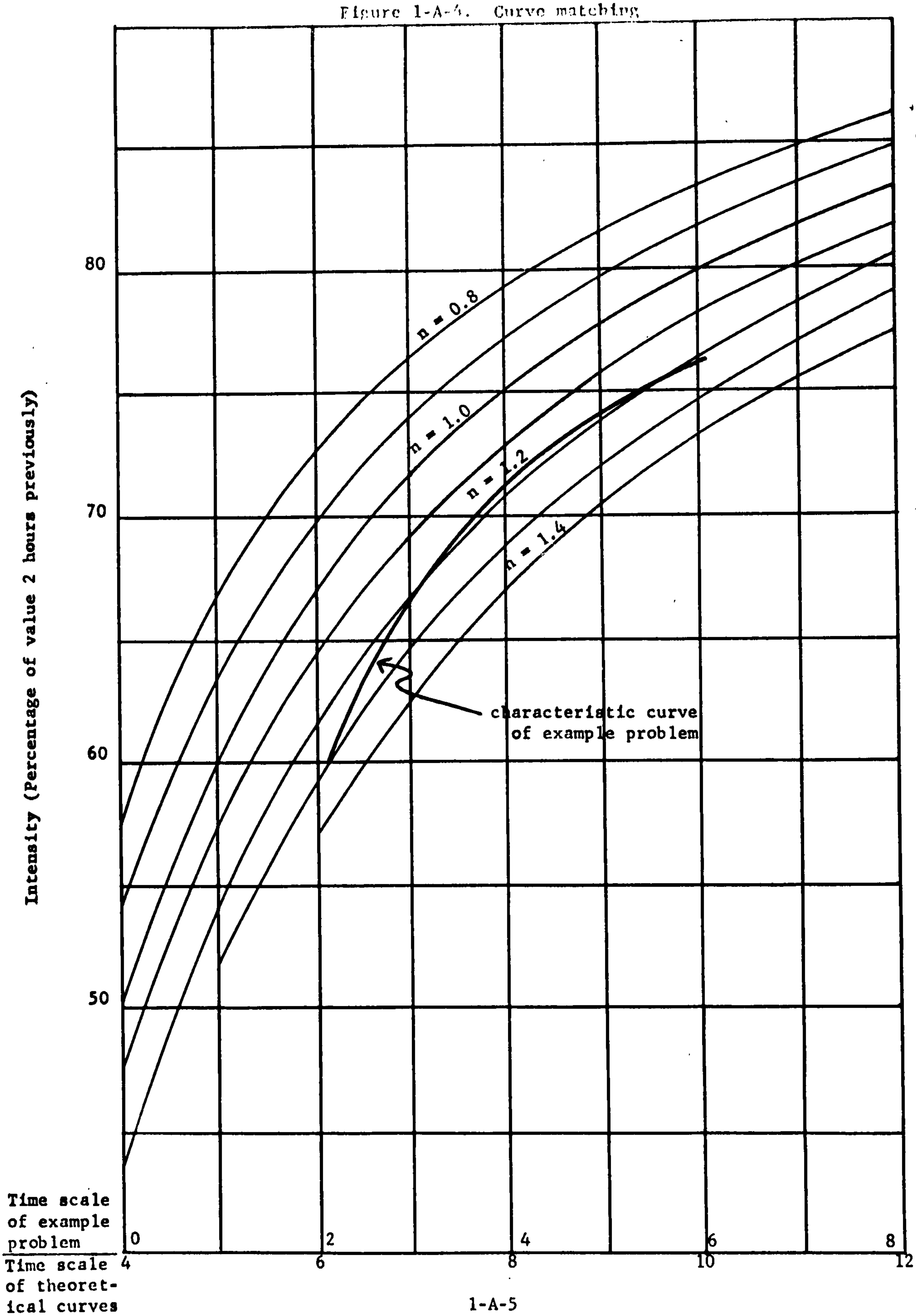


Figure 1-A-4. Curve matching



Step 4. Read off the value of n for the curve giving the best fit and determine the time value of the "characteristic curve" corresponding to zero time for the theoretical curves. For this example, n = 1.2 and zero time on the theoretical curves corresponds to a time approximately four hours prior to the first dose rate reading.

Step 5. The cumulative activity at this location can be considered to come from a single source, with burst time four hours prior to the first field reading, and decaying at a rate described by a decay constant (n) equal to 1.2. By the use of the decay nomogram shown in figure 1-A-5, the dose rate at any future time may be estimated. Using this figure, the predicted dose rates for 24 and 48 hours after the first reading may be calculated:

24 hours after 1st reading is 28 hours after calculated zero time.

1st reading (369 rad) is for 4 hours after calculated zero time.

Time factor = $\frac{28}{4}$ = 7

Radiation intensity factor for this time factor = 0.095.

Predicted dose rate for 24 hours after first reading 369 X 0.095 = 35 rad/hr.

The actual dose rate for this time is 35.5 rad/hr

48 hours after 1st reading is 52 hours after calculated zero time.

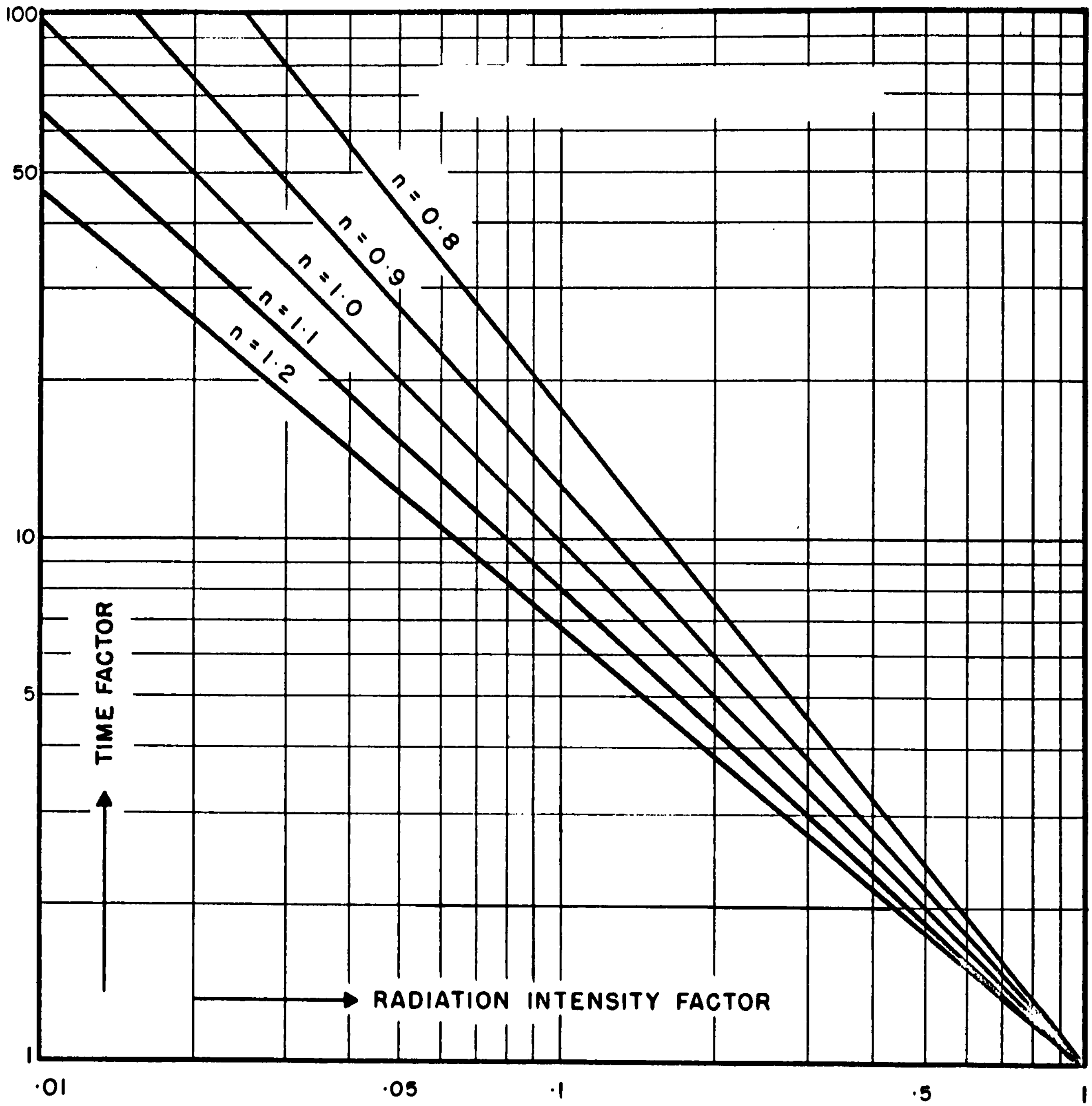
Time factor = $\frac{52}{4}$ = 13

Radiation intensity factor for this time factor = 0.045.

Predicted dose rate for 48 hours after first reading = 0.045 X 369 = 16.6 rad/hr.

The actual dose rate for this time is 17.2 rad/hr.

FIGURE 1-A-5 Decay Nomogram



APPENDIX 2 TO ANNEX A TO STUDY: Fallout from Multiple Surface Bursts

SAMPLE PROBLEM - COMPONENT METHOD

The problem below will illustrate the method of predicting future dose rates described in paragraph 8b of Annex A for the multiple burst situation.

Example: In an area where fallout has been received from two detonations, one at 0800 and one at 1100, the following dose rate readings were recorded.

TIME	0830	0900	0930	1000	1100	1130	1200
DOSE RATE (RAD/HR)	160	100	61	44	27	492	219

Predict the dose rates in this area for 0800 tomorrow and the day after tomorrow (24 and 48 hours after 1st burst).

Solution:

Step 1. The two contributors must first be separated. An examination of the measured dose rates indicates that the fallout from the first burst peaked prior to H + 1 hours (0900). Thus the reference dose rate (R_{1X}) for this portion of the fallout would be 100 rad/hour. The fallout from the second burst peaked prior to H + 1 hours for the second burst (1200) so the reference dose rate (R_{1Y}) for this portion would be 219 rad/hour minus the contribution from the first burst. R_{4X}, by single source methods, would be 19 rad/hr. Therefore, R_{1Y}, the reference dose rate for the second contribution would be 219-19 = 200 rad/hr.

Step 2. The total dose rate at 0800 tomorrow would be R_{24X} + R_{21Y}. Using single source methods:

R_{24X} = 2.2 rad/hr (R_{1X} = 100 rad/hr)

R_{21Y} = 5.2 rad/hr (R_{1Y} = 200 rad/hr)

R_{total} = 7.4 rad/hr

Step 3. The total dose rate at 0800 on the day after tomorrow would be R_{48X} + R_{44Y}. Using single source methods:

R_{48X} = 0.95 rad/hr (R_{1X} = 100 rad/hr)

$R_{45Y} = 2.05$ rad/hr ($R_{1Y} = 200$ rad/hr)

$R_{total} = 3.0$ rad/hr

This method is exact, so these values represent the actual values.

ANNEX B TO STUDY: Fallout from Multiple Surface Bursts (U)

REFERENCES

1. CDOG Study Project OSWD 57-2, USAOSWD, June 1961, "Tactical Potential of Fallout (U)."

2. Directive No. 525-6, HQ, USCONARC, 12 October 1961, "Tactical Use of Fallout (U)."

3. DA Pamphlet 39-3, Department of the Army, April 1962, "The Effects of Nuclear Weapons (U)."

4. Personal Communication, Mr. Caroll Oldham, Radiological Branch, U. S. Army Chemical Corps School, December 1961.

5. Report No. CD-6, Defence Research Board, Canada, December 1960, "A Note on the Prediction of Radiation Intensities Due to Fallout From a Single or From Multiple Nuclear Explosions (U)."

6. TM 3-210, Department of the Army, May 1962, "Fallout Prediction."

7. CDOG Study Project OSWD 61-1 (FY 63 Edition), USAOSWD, October 1962, "Army Requirements for Nuclear Weapons Effects Research (U)."

8. FM 3-( ), U. S. Army Chemical Corps School, Initial Manuscript, April 1962, "Operational Aspects of Radiological Defense."

ANNEX C TO STUDY: Fallout from Multiple Surface Bursts (U)

HEADQUARTERS
UNITED STATES ARMY COMBAT DEVELOPMENTS COMMAND
FORT BELVOIR, VIRGINIA

CDCCD-F

23 October 1962

SUBJECT: Combat Development Study Directive: Fallout from Multiple Surface Bursts

TO: Commanding Officer
U. S. Army Office of Special Weapons Development
Fort Bliss, Texas

1. General. It is requested that a study be undertaken which will determine the effects, on the army in the field, of fallout received concurrently from more than one contaminating nuclear detonation.

2. Objective and scope. To examine the effects of overlapping contamination fields of different ages on decay and total dose prediction. The adaptability of the current prediction system to this situation will also be examined.

3. References

a. DATC 101-1, "Prediction of Fallout and Radiological Monitoring and Survey (U)," DA, 9 December 1958, with Changes 1 and 2.

b. FM 101-31, "Nuclear Weapons Employment (U)," DA, July 1959, with Change 1.

c. DA Pam 39-3, "The Effects of Nuclear Weapons (U)," DA, April 1962.

d. TM 23-200, "Capabilities of Atomic Weapons (U)," DASA (forthcoming revision).

e. CD-6, "A Note on the Prediction of Radiation Intensities Due to Fallout from a Single or from Multiple Nuclear Explosions (U)," Defense Research Board, Canada, December 1960.

4. Assumption. The effects from enemy nuclear weapons will be identical to those from U. S. Weapons.

5. Guidance

a. The study will consider:

(1) Methods of decay and total dose calculations for fallout at one location resulting from more than one detonation.

(2) Overlapping fallout patterns from bursts separated in time, as well as in location.

(3) Fallout from all yields available or proposed for field army use, to include sub-kiloton yields.

b. The study will determine:

(1) The applicability of current methods of decay and total dose calculations to the situation resulting from overlapping fallout patterns.

(2) The adaptability of current fallout prediction techniques to fallout from multiple bursts.

6. Administration

a. Coordination. The draft study will be coordinated with the following agencies:

(1) U. S. Army Combined Arms Group.

(2) U. S. Army Air Defense CD Agency.

(3) U. S. Army Armor CD Agency.

(4) U. S. Army Artillery CD Agency.

(5) U. S. Army Engineer CD Agency.

(6) U. S. Army Infantry CD Agency.

(7) U. S. Army CBR CD Agency.

(8) U. S. Army Communications Electronics CD Agency.

(9) U. S. Army Combat Service Support Group.

(10) U. S. Army Medical Service CD Agency.

b. Suspense dates.

(1) Draft to above agencies for coordination: 1 December 1962.

(2) Final study: 1 February 1963.

c. Distribution.

(1) Hq, USACDC - 20 copies.

(2) Recommended distribution list will be submitted at the time the draft study is submitted for approval.

d. This project is assigned CDOG Project Nr OSWD 62-5, and appears in paragraph 1120-1 of the Combat Development Objectives Guide.

FOR THE COMMANDER:

/s/ Lewis V. Edner
LEWIS V. EDNER
Major, QMC
Asst Dir, Pers & Admin

Distribution:
K

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9. Commanding Officer, U. S. Army Engineer CD Agency, Fort Belvoir, Virginia.

10. Commanding Officer, U. S. Army Medical Service CD Agency, Fort Sam Houston, Texas.

11. Commanding Officer, U. S. Army Nuclear Defense Laboratory, Army Chemical Center, Maryland.

12. Commanding Officer, U. S. Naval Radiological Defense Laboratory, San Francisco, California.

ANNEX E TO STUDY: Fallout from Multiple Surface Bursts (U).

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